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FINAL ENGINEERING REPORT

EOGO TRIAXIAL SEARCH COIL MAGNETOMETER

JPL Contract 950257

ML/TN-2000. 341

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80 pages

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v

ABSTRACT

The EOGO Triaxial Search Coil Magnetometer was designed to make magnetic field fluctuation measurements in the frequency range of less than .01 cycle-per-second (cps) to above 1000 cps. The search coil sensor consists of a coil of 100,000 turns of wire wound on a nickel steel laminated core. The coil sensitivity is approximately 8 microvolt (μv)-seconds per gamma (γ) of magnetic flux. A low noise preamplifier with a gain of 110 is mounted in an auxiliary housing near the search coil. The main electronic assembly further amplifies the signal and performs a spectrum analysis which generates five outputs per axis, each a measure of the energy in a given frequency band. Other functions provided by this assembly are (1) real time data, (2) gain state data, (3) in-flight calibration (IFC), and (4) operating power conversion and regulation. Special equipment requirements included portable Bench Test Equipment (BTE) and Ground Support Equipment (GSE). These test equipments generate all spacecraft interface signals, provide calibration signals, and monitor the flight instrument outputs and test points.

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INTRODUCTION

This report summarizes the work carried out by Marshall Laboratories in compliance with JPL Contract 950257, EOGO Triaxial Search Coil Magnetometer.

The primary task of this contract was to develop, fabricate and test one (1) prototype and three (3) flight models of a Triaxial Search Coil Magnetometer, two (2) portable Bench Test Units, and two (2) Ground Support Equipments.

The primary function of the magnetometer is to measure low level magnetic field fluctuations in space. A spectrum analyzer is included to determine the frequency spectrum of the field fluctuations.

The flight instrument consists of five subassemblies. Three sensor subassemblies contain the search coils and a preamplifier subassembly contains three low noise preamplifiers. These are all mounted in an experiment package at the end of a long boom to reduce interference from spacecraft signals. The main equipment package, mounted in the spacecraft body, contains the remaining electronic circuitry.

The porable Bench Test Equipment was designed to perform complete laboratory bench checkout and calibration of flight instruments without the use of external test equipment.

The Ground Support Equipment was designed to check the flight instrument during spacecraft system tests.

This report contains detailed system, electrical and mechanical descriptions of the flight instrument, the Bench Test Equipment, and the Ground Support Equipment.

Appendix A contains Master Drawing Lists which can be used to locate and identify drawings related to the various equipments. 8

MAGNETOMETER DESCRIPTION

The following sections describe the EOGO Triaxial Search Coil Magnetometer including the mechanical design. The overall schematic diagram is shown in Marshall Laboratories Drawing 50357. Because of its relatively large size, this drawing is not included in this report. However, simplified and smaller schematic diagrams of the circuit under discussion are included.

System Description.

Figure 1 shows the block diagram of the EOGO Triaxial Search Coil Magnetometer which consists of three monoaxial magnetometer electronics, control circuits, in-flight calibration circuit, and power supply.

A monoaxial magnetometer electronics consists of a search coil sensor, preamplifier, Spectrum Channel, and Waveform Channel. This system is triplicated for the triaxial instrument. The sensor generates a voltage proportional to the rate of change of magnetic field along its axis. This signal is amplified by a low-noise preamplifier, passed through a special rejection filter, and presented to the Spectrum and Waveform Channels. The Spectrum Channel analyzes the magnetic field into frequency components through five bandpass filters with center frequencies of 10, 32, 100, 320, and 1000 cps. This information is transmitted as the peak field value. The Waveform Channel displays the magnetic field fluctuations between 0.01 to 1 cps. This information is transmitted as real time data and recorded on tape as non-real time data.

Control circuits are provided to increase the Waveform Channel bandwidth (0.01 to 64 cps) during the high data rate telemetry mode (64,000 bits/sec.). Telemetry BIT RATE, MODE and SWITCH signals, supplied by the spacecraft, are used to control the bandwidth. Provisions

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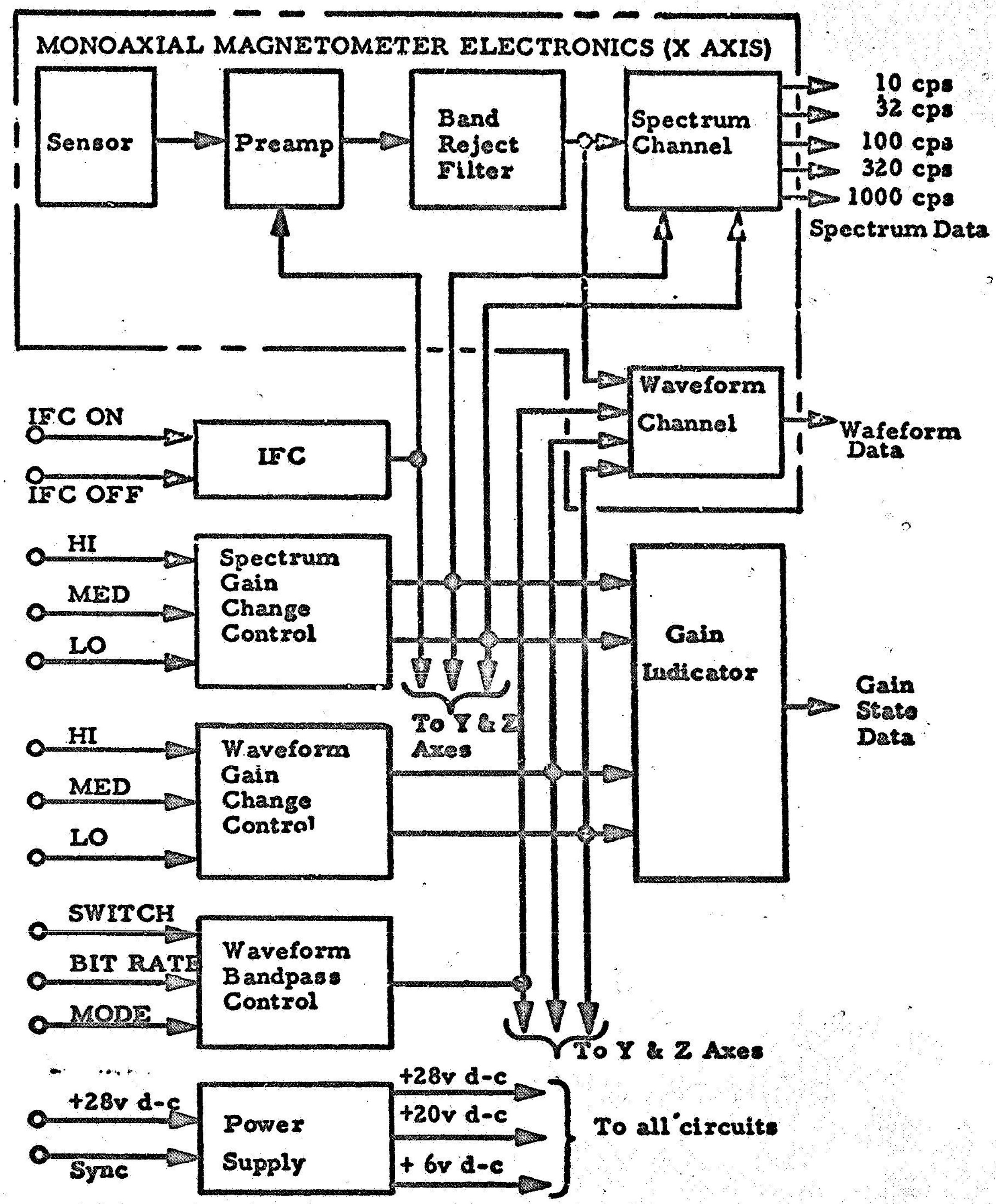

NOTE: Blocks in dashed line are triplicated.

Figure 1. Functional Block Diagram, EOGO Triaxial Search Coil Magnetometer.

are also made to control independently the gain of the Spectrum and Waveform Channels to high, medium, or low. The Gain Indicator sums the Spectrum and Waveform gain change signals and generate a signal that indicates the gain state and verifies the receipt of command signal.

The in-flight calibrate (IFC) circuit provides calibration signals to the preamplifier to check the sensitivity of the Spectrum and Waveform channels. One ground command turns the calibration signals ON and another turns them OFF.

A power supply provides power to the magnetometer. Primary spacecraft voltage is +23.5 to +33.5v d-c. It is converted to regulated +20 to +6v d-c by a d-c - d-c converter which is synchronized to a 2461 cps spacecraft signal.

Details of the various main functional blocks are discussed below.

Monoaxial Magnetometer Electronics.

Figure 2 shows the basic monoaxial magnetometer electronics which consists of a search coil sensor, preamplifier, Spectrum Channel and Waveform Channel. Magnetic field fluctuation is detected by the search coil sensor, amplified by the preamplifier, and passed through a 400 cps Band Reject Filter. The filtered signal is then amplified and analyzed for its frequency component content by the Spectrum Channel and applied to the Waveform Channel for low frequency waveform analysis.

Amplifier gain and bandwidth control functions are discussed in a later section.

Search Coil Sensor: The function of the search coil sensor is to detect fluctuation of the ambient magnetic field component directed along the coil axis. A voltage is induced which is proportional to the rate of change

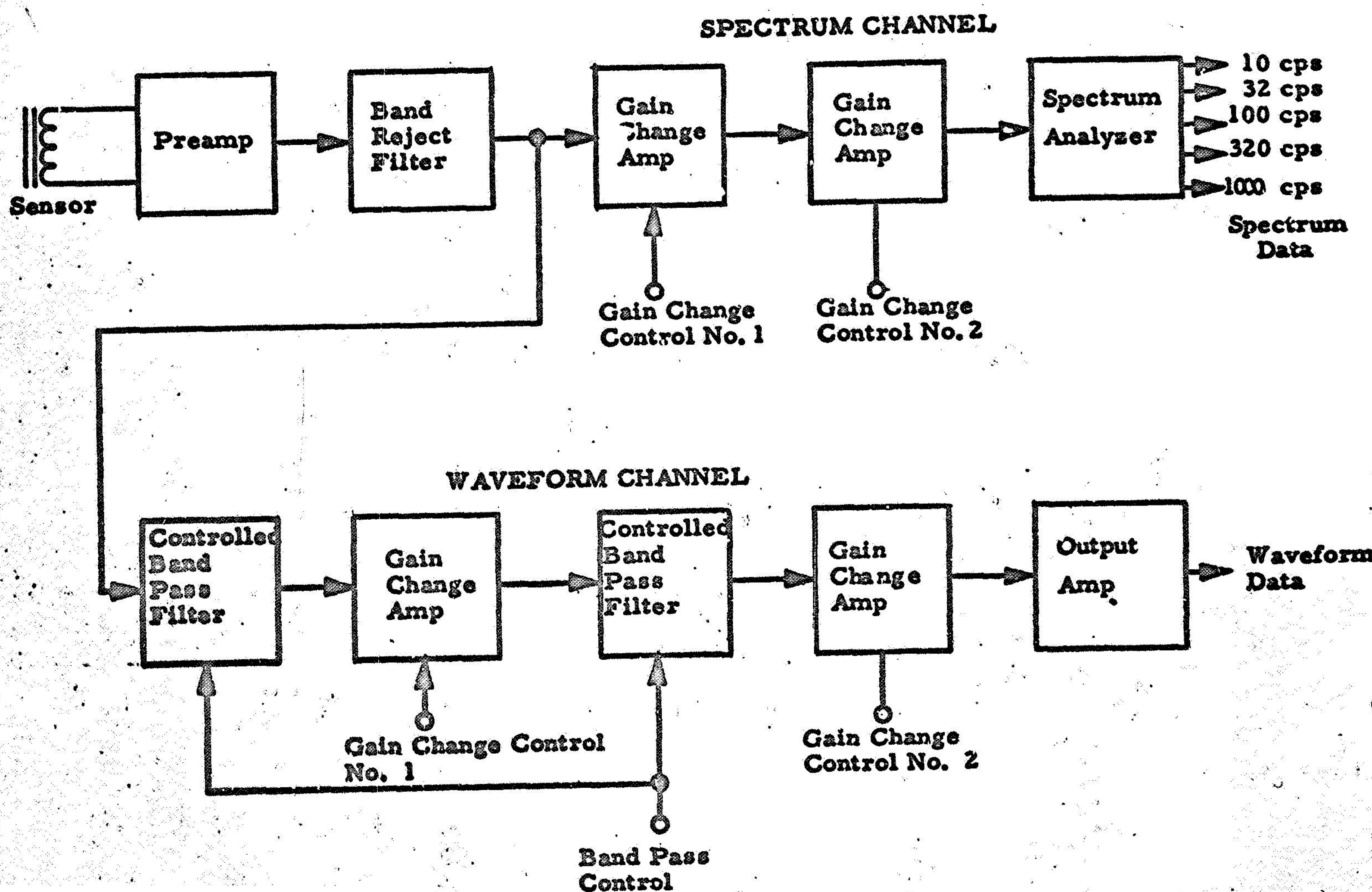

Figure 2. Monoaxial Magnetometer Electronics Functional Block Diagram.

of the field. For sinusoidal field fluctuations, the induced voltage is

$$e = S f H_m \cos 2 \pi f t$$

where S = sensor sensitivity in $\mu v/\gamma$ - cps

f = frequency in cps

H_m = Maximum field intensity

Nominal sensitivity is 8 $\mu v/\gamma$-cps and resonant frequency is about 700 cps. Frequency response curve of one of the units is shown in Figure 3.

Each sensor is made of an induction coil wound on laminated sheets of high permeability core material made of 50/50 nickel iron alloy. The core dimensions are 0.25" x 0.25" x 10.5". The induction coil actually consists of eight smaller coils, each with 12,500 turns of teflon-insulated No. 47 AWG wire, connected in series aiding. The three search coils are mounted orthogonally in the EOGO spacecraft Experiment Package No. 5.

Preamplifier: The preamplifier is designed for high input impedance, low input capacity, and low noise characteristics. Typical noise level with source impedance of 100K Ω (such as the search coil) in the frequency band of 0.01 to 3 cps is in the order of 1 μv/cps or less. Amplifier gain is nominally 110. Three preamplifiers are packaged in a housing, which also includes a thermally controlled heater, and mounted near the search coils to minimize cable capacity.

Figure 4 shows a simplified schematic of a monoaxial preamplifier. The unit consists of a three stage d-c amplifier with negative series feedback to stabilize operating characteristics. The input stage, Q1, is a field effect transistor, selected for low noise characteristics at low and

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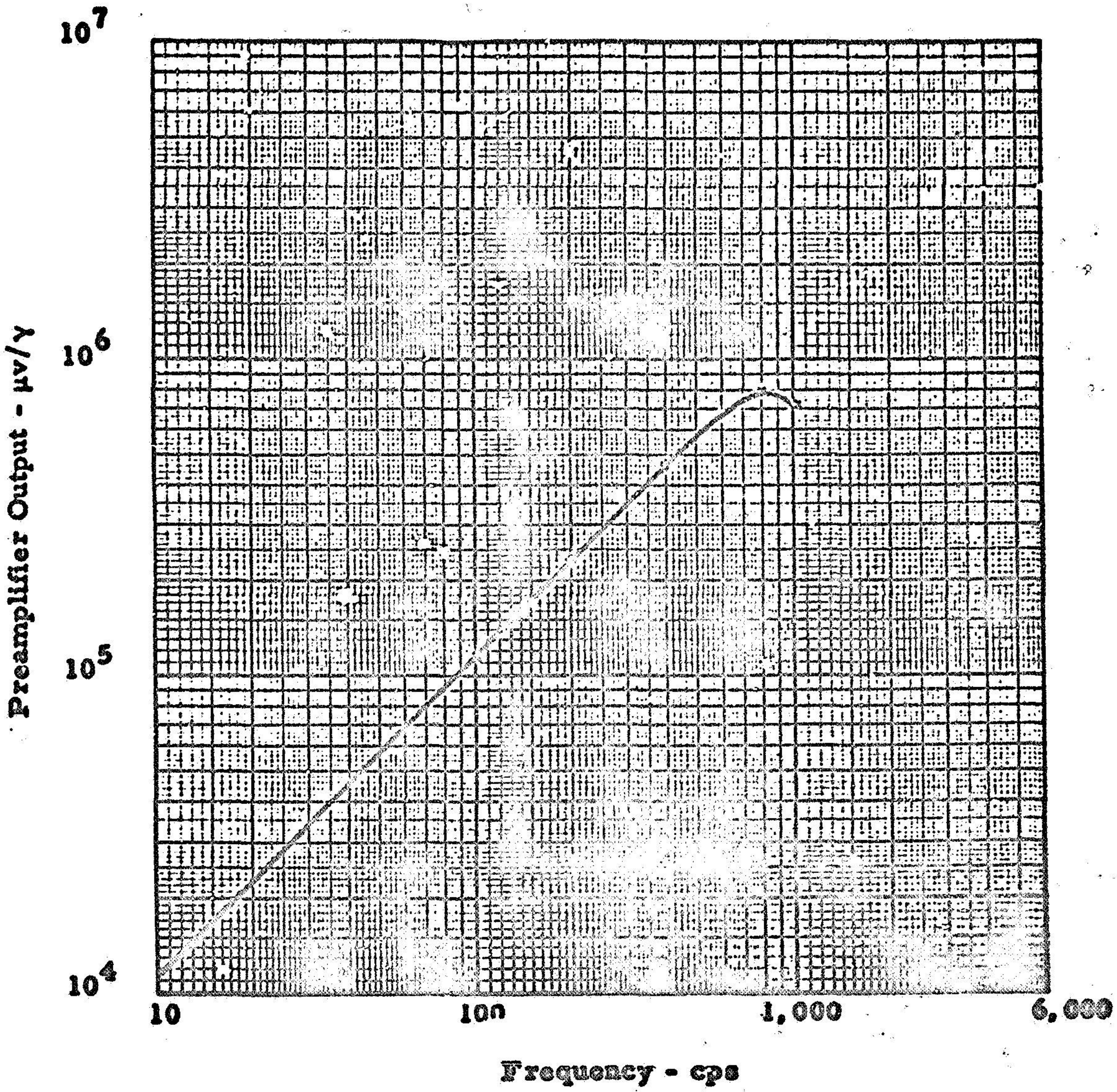
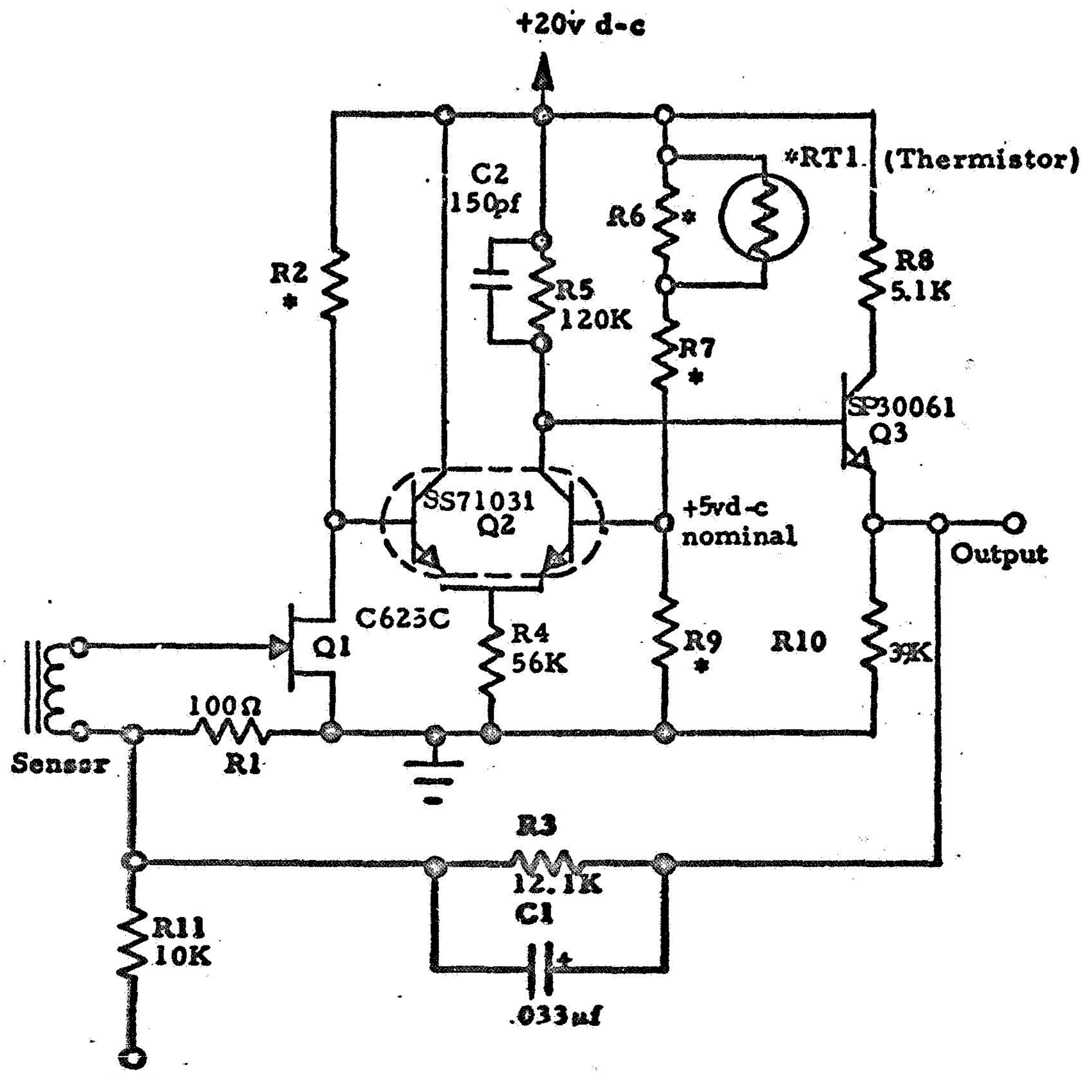


Note: Preamplifier gain is 110.
Preamplifier S/N 4
Probe S/N 13

Figure 3. Sensor/Preamp Frequency Response



*Denotes selected components

Figure 4. Preamplifier Simplified Schematic

medium frequencies. Q1 output signal is further amplified by differential amplifier, Q2, and emitter follower, Q3. Nominal open loop gain is 2000. Transistors used for Q2 and Q3 are also selected for low noise characteristics. Single lead compensation in the amplifier RC network stabilizes the feedback and provides necessary gain and phase margin to prevent amplifier oscillation. A thermistor network in the differential amplifier reduces temperature sensitivity of the preamplifier. The compensating network provides a bias voltage as a function of temperature to offset temperature effects in the Field Effect Transistor. Compensated operating temperature range is in the order of 40°C.

Figure 5 shows the heater schematic. The heater consists of a thermistor bridge circuit driving a three transistor amplifier. A one watt heater element supplies the necessary thermal energy to maintain constant temperature. The preamp/heater assembly is wrapped with insulating material and mounted in its housing. Operating temperature of the heater is set at 20°C ± 5°C.

Band Reject Filter: The Band Reject Filter consists of a 400 cps rejection filter and a low pass filter with cutoff at 1000 cps. Attenuation is greater than 50 db at 400 cps and 2500 cps. A frequency response curve is shown in Figure 6. This filter is employed to prevent 400 cps magnetic fields generated by the spacecraft from saturating the magnetometer electronics system. Since the magnetometer system response is limited to 1000 cps, the Band Reject Filter is also designed for cutoff beyond 1000 cps.

The output signal of the filter is then applied to the Spectrum and Waveform Channels.

Spectrum Channel: The primary function of the Spectrum Channel is to determine the frequency components of the measured magnetic field fluctuation in the frequency bands of 10, 32, 100, 320, and 1000 cps.

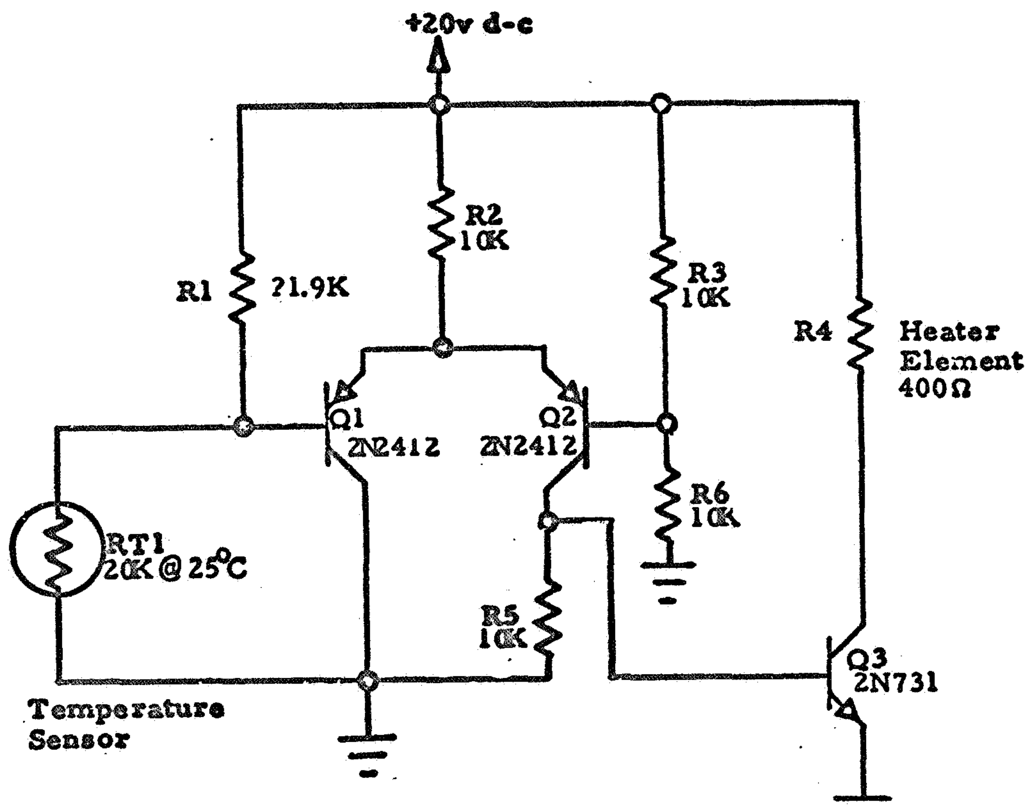


Figure 5. Heater Simplified Schematic

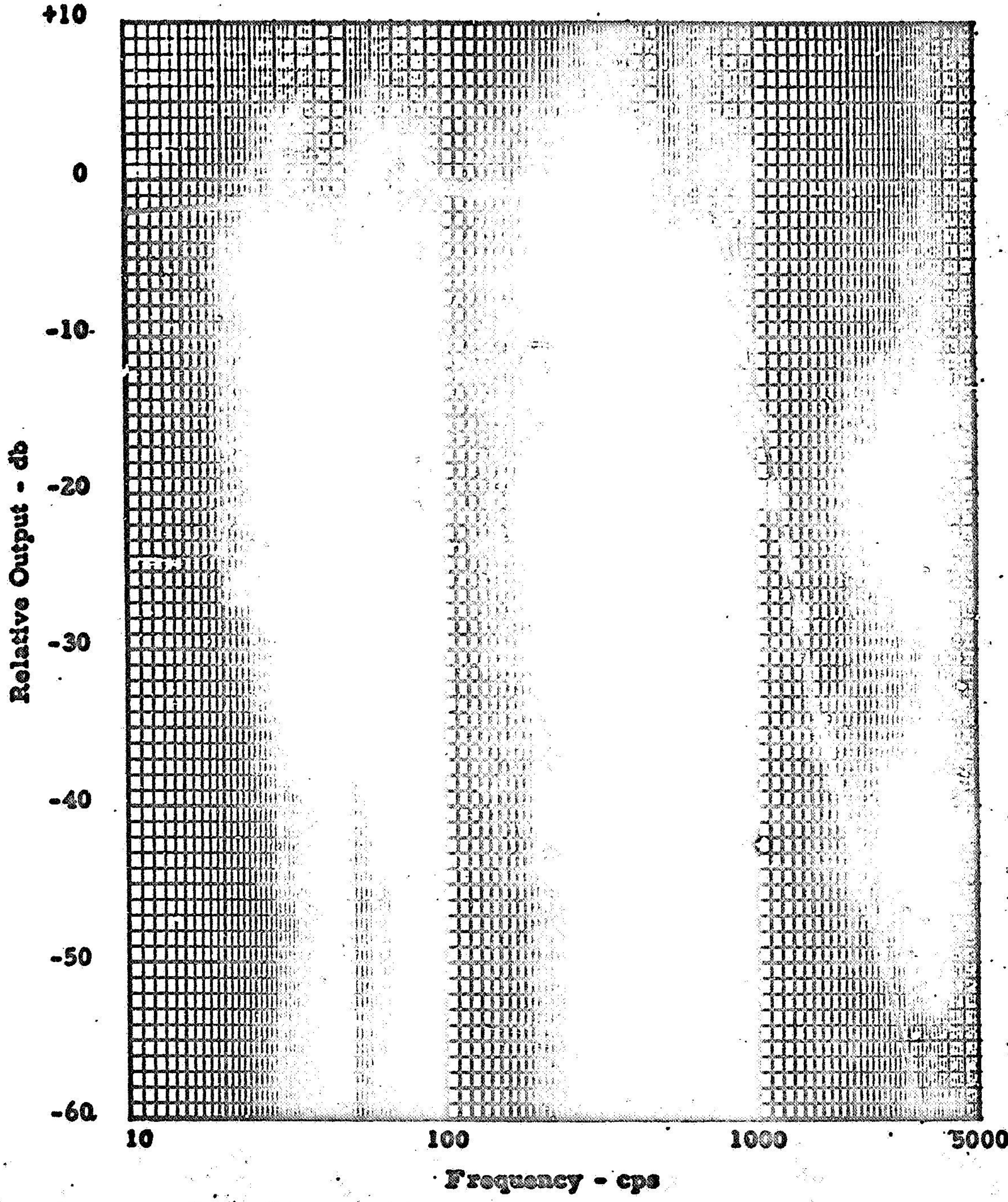


Figure 6. Band Reject Filter Frequency Response

Spectrum analysis is performed by the Spectrum Analyzer which consists of five similar bandpass amplifiers. The difference between the five amplifiers is that different values of capacitors alters center frequency. The data signal from the Band Reject Filter is amplified by the Gain Change Amplifier whose gain is controlled via ground command link. Overall channel gain can be changed to be 2, 20, or 200.

Figure 7 shows a schematic diagram of the Gain Change Amplifier. Each amplifier stage provides gain of 1.4, or 14, depending on the gain control voltage level. The amplifier consists of a d-c coupled negative feedback amplifier. Closed loop gain is determined by the ratio of R6 to R4. Q3 is a static switch that parallels R5 with R4 when the gain control voltage level is zero. Amplifier gain is therefore increased when the control voltage level is low and vice versa. Two identical amplifier stages provide three levels of gain in accordance with the following table.

Spectrum Gain Change Command Signals			Spectrum Gain Control No. 1	Spectrum Gain Control No. 2	Spectrum Channel Overall Gain
Hi	Med	Lo			
1	0	0	0	0	14 x 14 = 200
0	1	0	0	+ 20v	14 x 1.4 = 20
0	0	1	+ 20v	+ 20v	1.4 x 1.4 = 2

The missing control combinations never occur because only one command at a time is transmitted.

A typical bandpass amplifier is shown in Figure 8. The input coupling network, consisting of C1, R1, C2, and the equivalent amplifier input impedance, provides a low Q band pass filter characteristic. This network is characterized by the following transfer function:

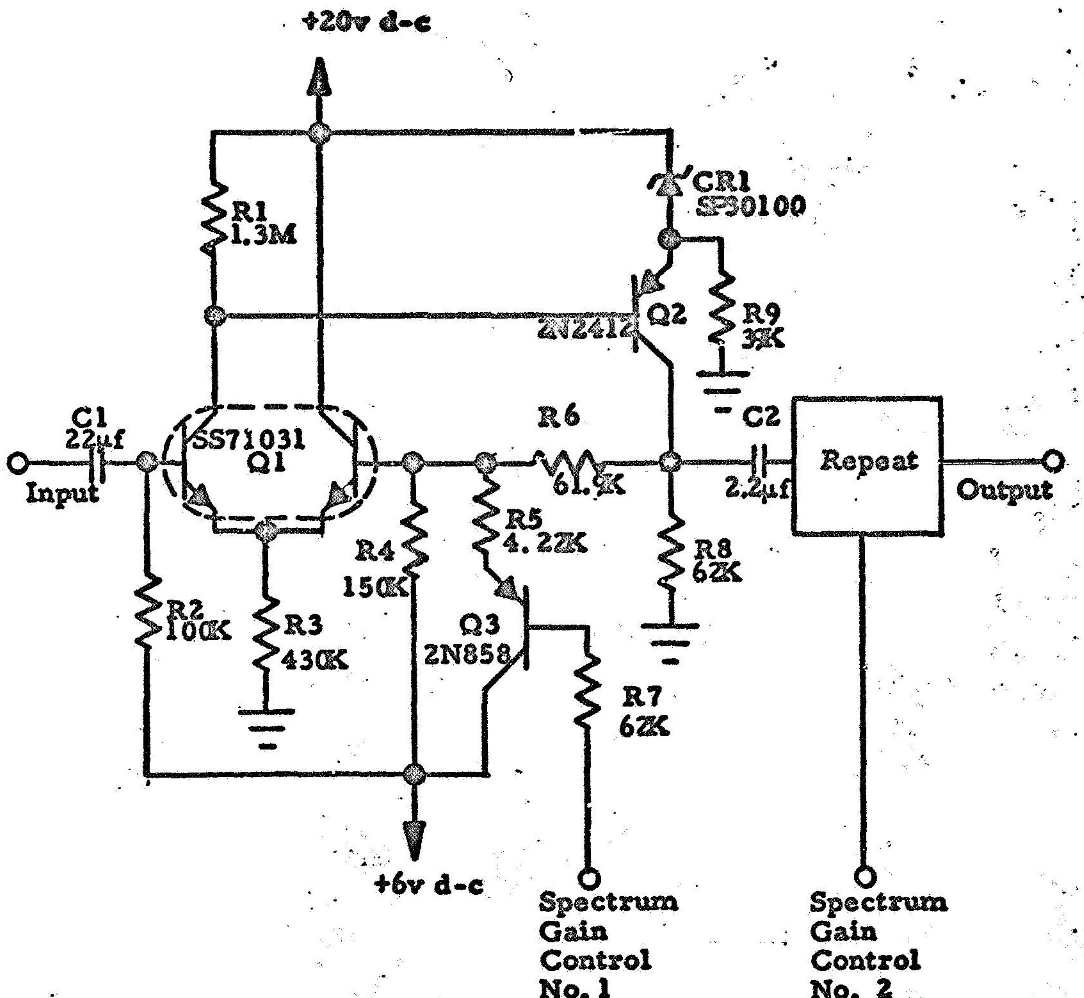


Figure 7. Simplified Schematic Diagram of Spectrum Gain Change Amplifier

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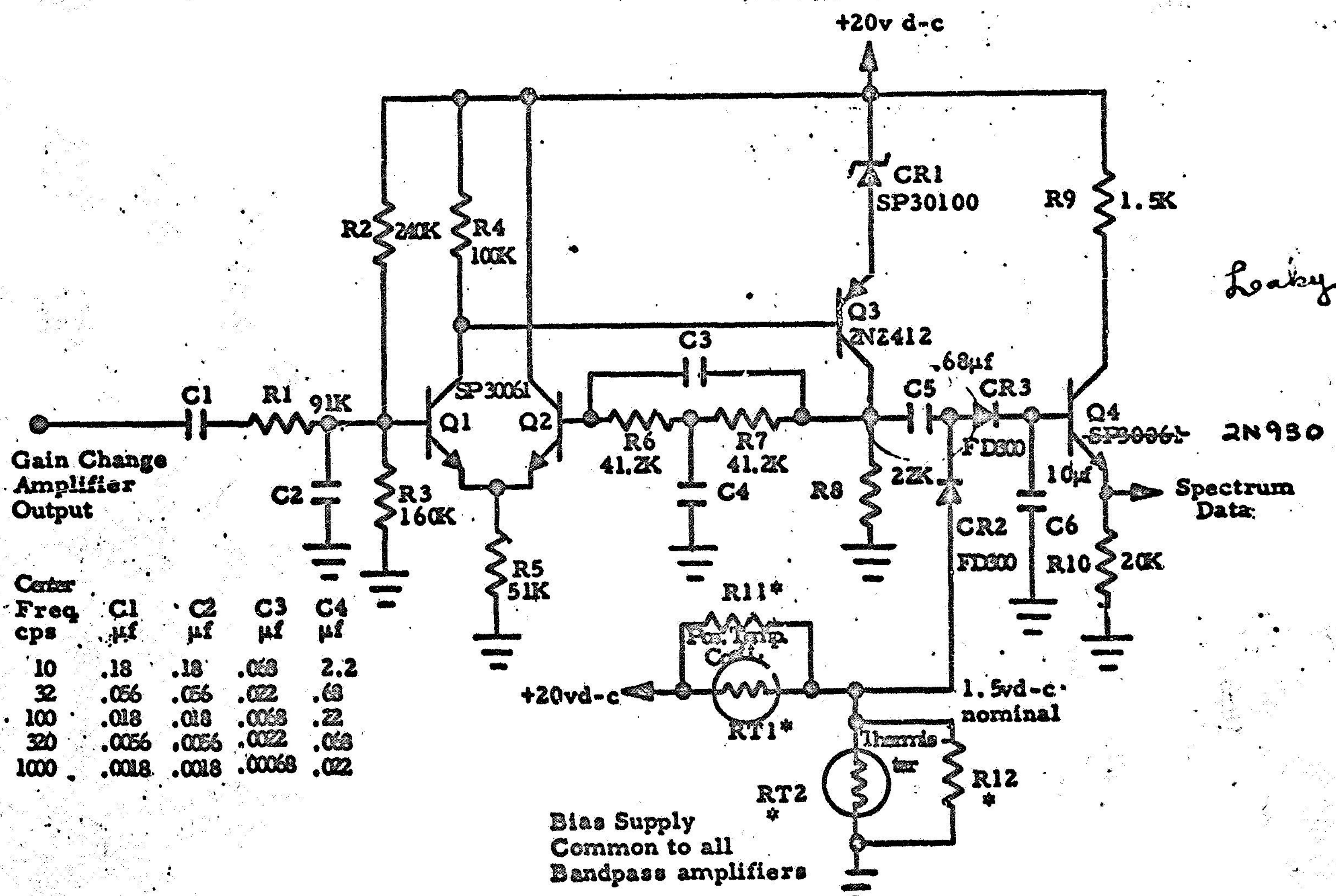

Center Freq cps	C1 μf	C2 μf	C3 μf	C4 μf
10	.18	.18	.068	2.2
32	.056	.056	.022	.68
100	.018	.018	.0068	.22
320	.0056	.0056	.0022	.068
1000	.0018	.0018	.00068	.022

*Denotes selected components

Figure 8. Simplified Schematic of Spectrum Analyser Band Pass Amplifier.

$$\frac{e_o(s)}{e_i(s)} = \frac{\tau S}{1 + 3\tau S + \tau^2 S^2}$$

where $\tau = R1C1$

$$\doteq \frac{R2R3}{R2 + R3} C2$$

The band pass amplifier consists of a d-c coupled negative feedback amplifier with a bridge T filter in the feedback loop. The amplifier transfer function is:

$$\frac{e_o(s)}{e_i(s)} = \frac{1 + 0.064\,\tau S + \tau^2 S^2}{1 + 1.064\,\tau S + \tau^2 S^2}$$

where $\tau = R7\sqrt{C3C4}$

for $R6 = R7$.

The time constants for the five band pass amplifiers are listed below:

Center Frequency	τ
10 cps	16×10^{-3} sec
32 cps	5.2×10^{-3} sec
100 cps	1.6×10^{-3} sec
320 cps	0.52×10^{-3} sec
1000 cps	0.16×10^{-3} sec

This type of filter provides narrow bandwidth (Q of 3.3) but does not provide sufficient attentuation at the skirts. The input skirt filter is therefore necessary.

The filtered signal is peak-to-peak detected and presented to the spacecraft telemetry through an emitter follower stage to present a low output impedance. A bias voltage is used in the detector to overcome threshold characteristics of the base-to-emitter characteristics of the emitter follower. Since the base-to-emitter junction and diode drops are thermally sensitive, the bias voltage is also made to be temperature dependent to compensate for output level variations with temperature.

C6 provides low pass filtering of the detected signal. This network is characterized by the following transfer function.

$$\frac{e_o(s)}{e_i(s)} = \frac{A}{1 + \tau S}$$

A is a non-linear function of the detector network and can be approximated by

$$e_o = 2.4\, e_i - 0.5 + 0.55\, \mathcal{E}^{-e_i/0.2}$$

The filter time constant, τ, is much less when charging than discharging. When C6 is discharging, τ is the product of C6 and equivalent input impedance of Q4 which is approximately β times R10. When C6 is charging, τ is approximately the product of C6 and impedance of CR3 in series with output impedance of the band pass amplifier. For all channels τ charging is approximately 0.2 seconds and τ discharging is approximately 40 seconds.

The final spectrum voltage is an analog voltage between 0 and +5 volts proportional to the amplitude of magnetic field frequency component in the associated channel being measured. The combined rejection filter and analyzer frequency response is shown in Figure 9.

Waveform Channel: The Waveform Channel is designed to provide measurement of magnetic field fluctuations in the frequency range of 0.01 to 1 cps or .01 to 64 cps depending on control conditions, i.e., rate of data transmission.

The Waveform Channel consists of two identical controlled band pass filter circuits, two gain change amplifiers, and an outputs amplifier stage. Bandwidth as a function of command signals is shown in the table of Figure 10. "Narrow band" refers to 1 cps cutoff and "wide band" refers to 64 cps cutoff. The logic circuit required to generate the appropriate band pass control signal is discussed in a later section. Two Gain Change Amplifiers, identical to the Spectrum Gain Change Amplifiers are employed to provide high, medium, or low gain setting via ground command link. The relation between command signal and gain setting is shown below.

Gain Change Waveform Command Signals Hi	Med.	Lo	Waveform Gain Control No. 1	Waveform Gain Control No. 2	Waveform Gain Change Amplifier Gain
1	0	0	0	0	14 x 14 =200
0	1	0	0	20v	14 x 1.4 = 20
0	0	1	20v	20v	1.4 x 1.4 = 2

The missing control combinations never occur because only one command at a time is transmitted. The output amplifier gain is nominally 5. Hence, the overall gain of the Waveform Channel can be changed to be 10, 100, or 1000 for high, medium or low gain setting, respectively.

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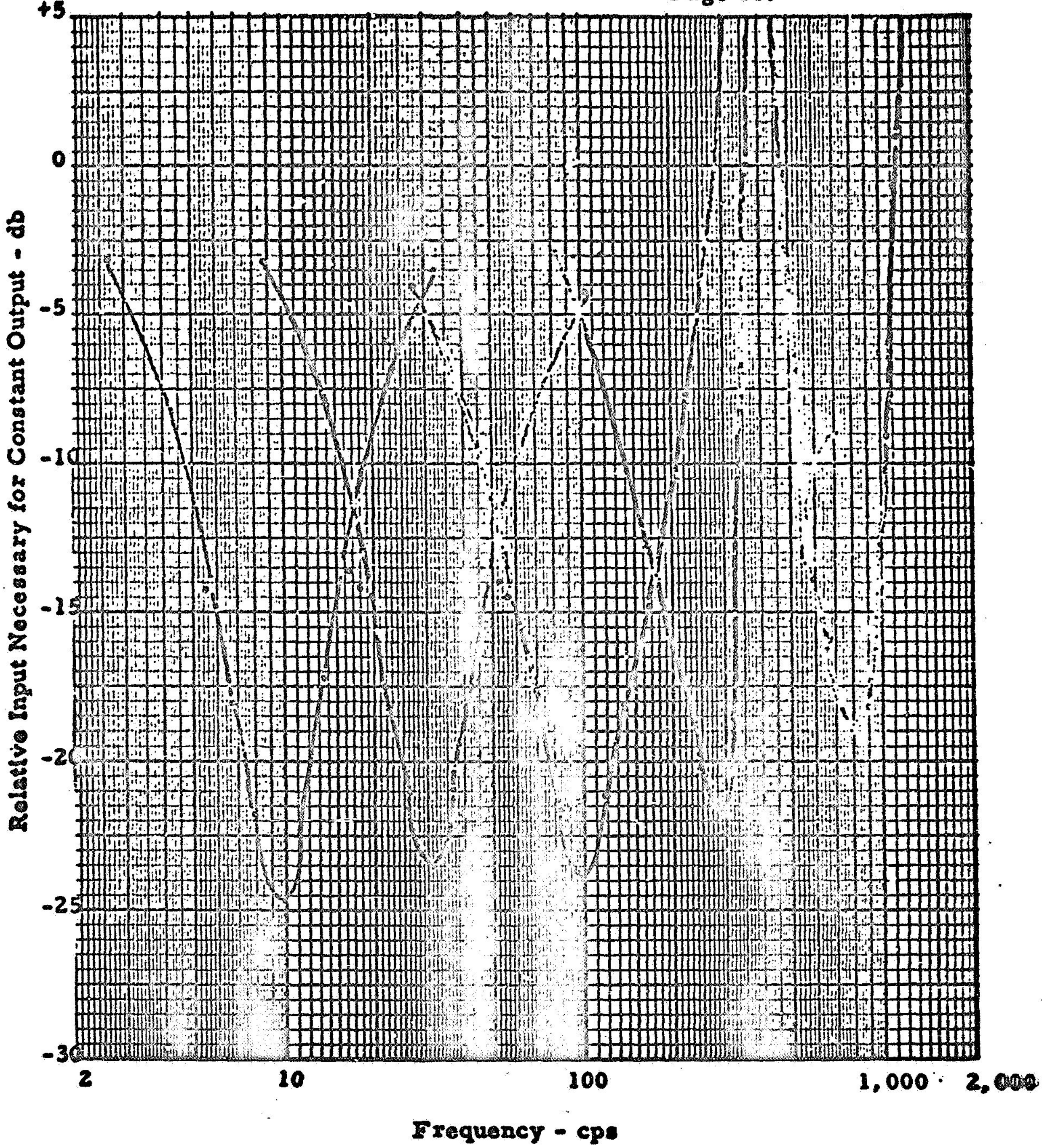

Figure 9. Spectrum Channel Combined Frequency Response

COMMAND SIGNALS				
Mode	Switch	Bit Rate K bps	Band Pass Control Signal	Bandwidth
0	0	1	0	Narrow
0	0	8	0	Narrow
0	0	64	0	Narrow
1	0	1	0	Narrow
1	0	8	0	Narrow
1	0	64	1	Wide
0	1	1	0	Narrow
0	1	8	0	Narrow
0	1	64	1	Wide
1	1	1	0	Narrow
1	1	8	0	Narrow
1	1	64	1	Narrow

Figure 10. Bandwidth versus command signals table.

Figure 11 shows a simplified schematic diagram of the waveform band pass and gain change circuit. The output signal of the Band Reject Filter is applied to the first band pass control circuit. Q1 is a static switch controlled by the Band Pass Control signal. With Q1 nonconducting, the high frequency cutoff point is determined by R1C1 (nominally 128 cps). With Q1 conducting, C2 is placed in parallel with C1 and the cutoff frequency is reduced to about 2 cps. Two of these controlled band pass filter networks are employed to provide 12 db/octave roll off characteristics. Low frequency cutoff is determined by coupling capacitors C3, C4, and C5 and their respective equivalent load resistance. The low frequency cutoff of each coupling network is about .005 cps.

Figure 12 shows the schematic diagram of the waveform output amplifier which is designed for stable d-c bias level, stable gain, and low output impedance. The amplifier consists of two stages of d-c coupled differential amplifier with negative feedback for gain stability. Overall a-c gain is nominally five. D-C feedback is provided by Q4 and CR1 which effectively maintains constant current through Q1. Nominal zero field bias level is +2.50 volts and is derived by attenuating the +6v supply voltage through R1 and R2. Full scale data output voltage is 5v p-p superimposed on the +2.50v bias level.

Control Circuits.

Three control circuits are required to convert command signals to appropriate control signals for the magnetometer electronics. Control signals are generated to (1) change gain of the Spectrum Channel, (2) change gain of the Waveform Channel, and (3) change Waveform Channel bandwidth. Part of the signals are also used in conjunction with the IFC circuit as will be discussed later.

Waveform Channel Gain Change: Two control signals are required to operate the Waveform Gain Change Amplifiers. To increase gain, the

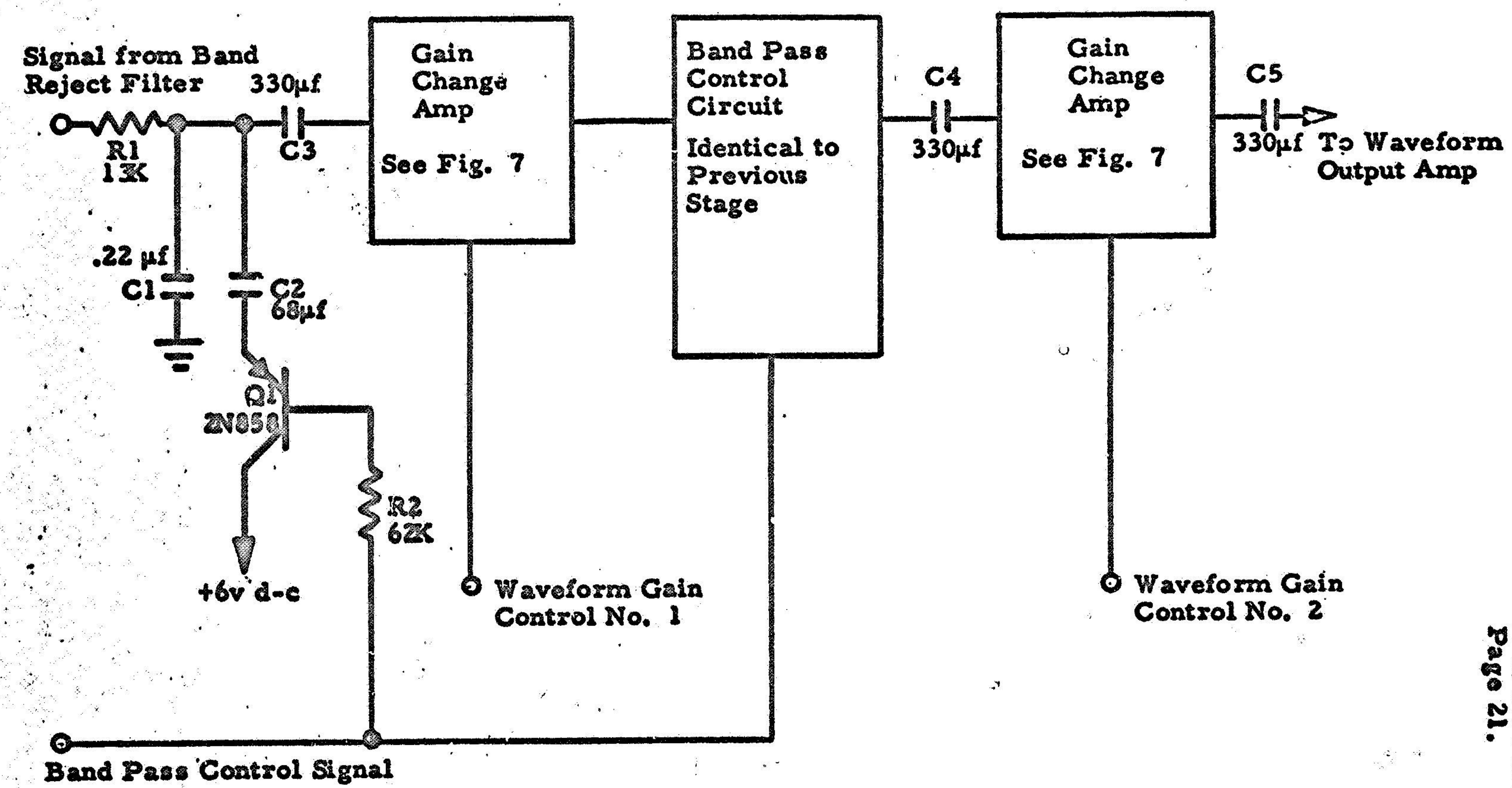

Figure 11. Simplified Schematic Diagram of Waveform Band Pass and Gain Change Circuit.

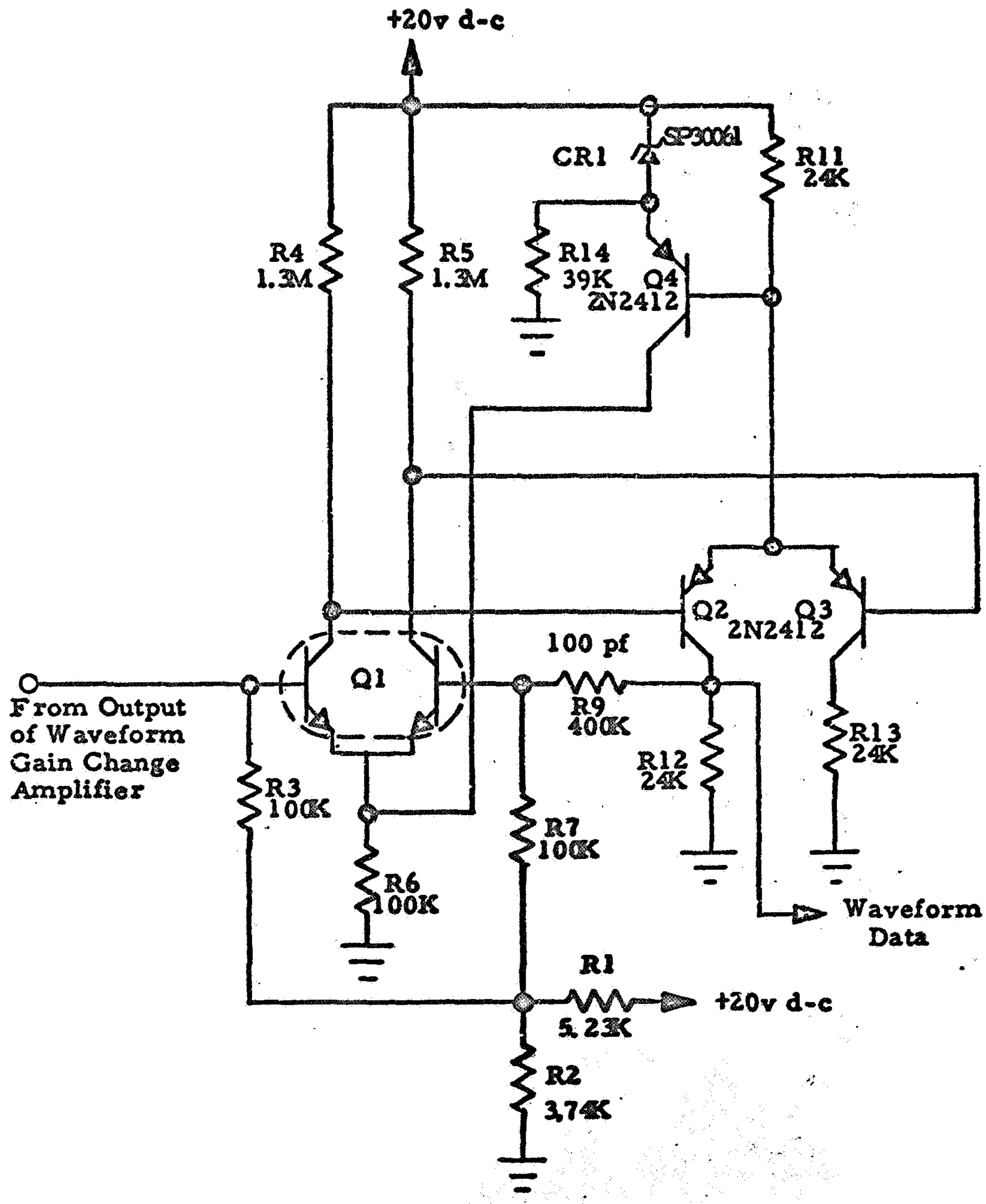

Figure 12. Simplified Schematic Diagram of Waveform Output Amplifier

control signal must be 0v and for decreasing gain the control signal must be +20v. The command signals are controlled via ground communication link. Three command signals allow high, medium, or low gain setting.

Figure 13 shows the simplified control circuit that converts the command signals to appropriate gain change control signals. The command signals are 50 milliseconds relay closure that are generated by the spacecraft system. Latching relays are therefore employed which consume no power during static conditions. Diode logic circuits appropriately switch the relays depending on the command signal received. Note that the relation of command signal to control signal as shown in the previous table is satisfied. The missing combinations never occur because only one of the commands at a time is transmitted to the spacecraft.

A separate set of relay contacts are used in operating the IFC circuit as will be discussed later.

The control signals are applied to the Gain Indicator as will be discussed later.

<u>Spectrum Channel Gain Change</u>: The control circuit for the Spectrum Channel Gain Change Amplifiers is identical to the previously discussed Waveform Channel Gain Change control circuit with the exception that IFC control functions are not generated. The command signals for the Spectrum Channel are also generated via ground communication link. The control signals are also routed to the Gain Indicator.

<u>Waveform Channel Band Pass Control</u>: The function of the Band Pass control circuit is to generate a +20v signal when real time data is being transmitted at telemetry rate of 64,000 bps to increase Waveform

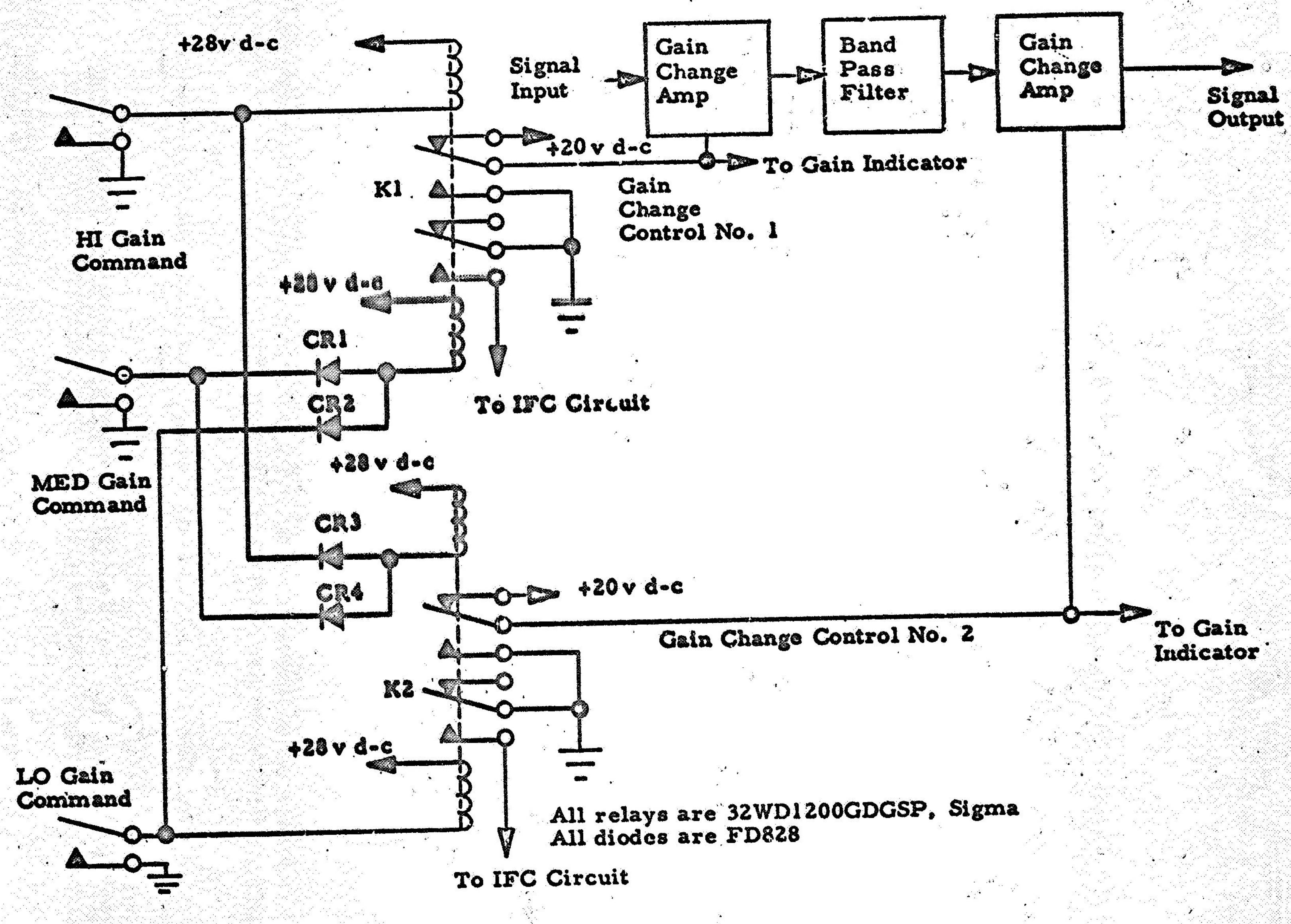

Figure 13. Simplified Control Circuit for Waveform Channel Gain Change Amplifiers.

Channel bandwidth. Three spacecraft information signals are used to detect the desired condition. These signals are MODE, SWITCH, and BIT RATE.

The MODE signal tells the equipment group whether its data is being recorded or being transmitted on real time. The following table shows the relation between MODE signal and equipment group.

Mode	Mode Signal Level	Group 1	Group 2
1	+ 3.9v to +9v	Real Time	Record
0	0v to + .6v	Record	Real Time

When one group is being transmitted in real time, the other group is being recorded at a comparatively low rate. The Triaxial Search Coil Magnetometer is included in both groups.

The SWITCH signal tells which of the groups is being transmitted in real time as shown in the following table.

Switch	Switch Signal Level	Real Time Transmission
0	0 to +2v	Group 1
1	+7v to +33.5v	Group 2

The BIT RATE signal tells the telemetry data readout rate as shown in the following table.

Bit Rate K bps	Bit Rate Signal Level
1	+3.3v ± 5%
8	+5.1v ± 5%
64	+7.5v ± 5%

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The possible combinations are tabulated in Figure 14. The control circuit must detect the condition when Group 1 and Group 2 are being transmitted at 64,000 bps.

Figure 15 shows a simplified schematic diagram of the band pass control circuit that detects the desired conditions and generates a control signal to operate the Waveform Channel Band Pass circuit described previously. The output amplifier essentially is a threshold device that generates a +20v signal when the input signal is equal to the 64,000 bps signal level. For all other conditions, the output voltage is zero.

The logic circuit provides a signal that turns Q2 OFF when the MODE signal is 1 and SWITCH signal is zero or when MODE signal is zero and SWITCH signal is 1. Then, as a net result, wide bandwidth control signals are generated when

Mode = 1
Switch = 0
Bit Rate = 64,000 bps

or when

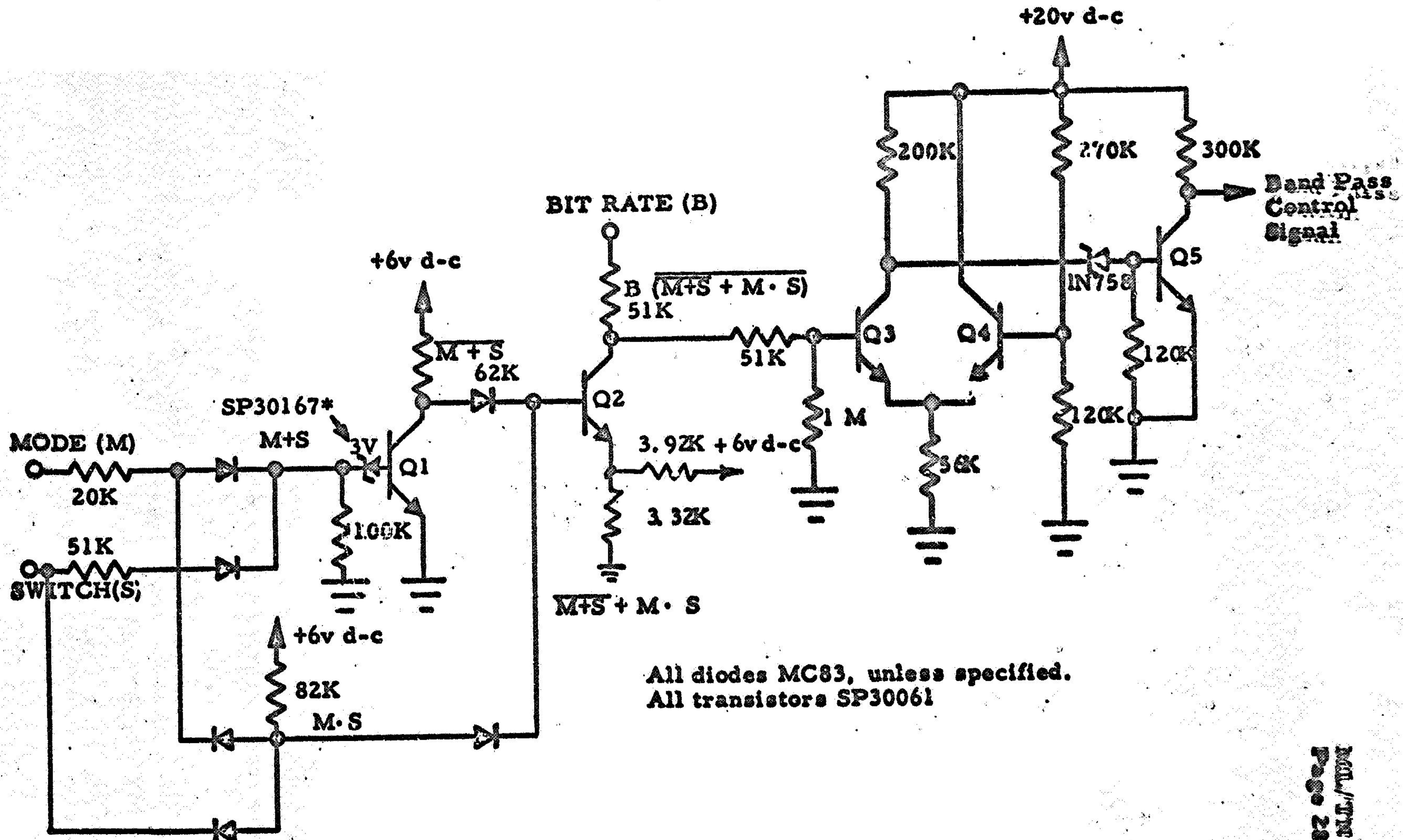
Mode = 0
Switch = 1
Bit Rate = 64,000 bps

which are the desired conditions.

Gain Indicator: Figure 16 shows a simplified schematic diagram of the Gain Indicator circuit. Its function is to provide an analog voltage that identifies the gain settings of the Waveform and Spectrum Channels.

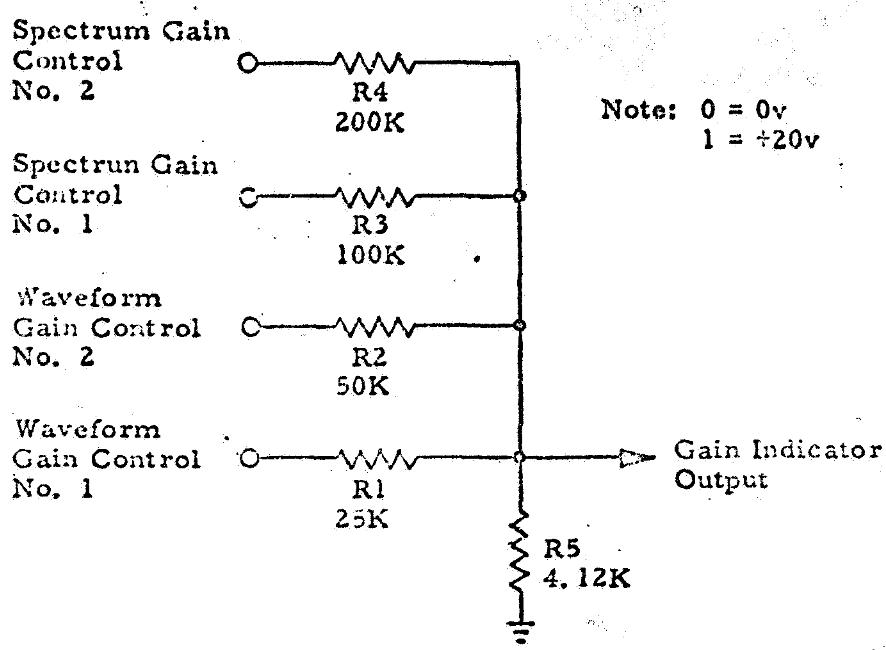
MODE	GROUP 1	GROUP 2	SWITCH	REAL TIME TRANSMISSION	BIT RATE K bps	BANDWIDTH
1	Real Time	Record	0	Group 1	1	Narrow
1	Real Time	Record	0	Group 1	8	Narrow
1	Real Time	Record	0	Group 1	64	Wide
1	Real Time	Record	1	Group 2	1	Narrow
1	Real Time	Record	1	Group 2	8	Narrow
1	Real Time	Record	1	Group 2	64	Narrow
0	Record	Real Time	0	Group 1	1	Narrow
0	Record	Real Time	0	Group 1	8	Narrow
0	Record	Real Time	0	Group 1	64	Narrow
0	Record	Real Time	1	Group 2	1	Narrow
0	Record	Real Time	1	Group 2	8	Narrow
0	Record	Real Time	1	Group 2	64	Wide

Figure 14. Tabulation of waveform channel bandpass control command signal combinations.



All diodes MC83, unless specified.
All transistors SP30061

Figure 15. Simplified Schematic Diagram of Waveform Channel Bandpass Control Circuit.



WG No. 1	WG No. 2	SG No. 1	SG No. 2	Gain Indicator Output
0	0	0	0	0v
0	0	0	1	--
0	0	1	0	.625
0	0	1	1	.937
0	1	0	0	--
0	1	0	1	--
0	1	1	0	--
0	1	1	1	--
1	0	0	0	2.50
1	0	0	1	--
1	0	1	0	3.125
1	0	1	1	3.44
1	1	0	0	3.75
1	1	0	1	--
1	1	1	0	4.37
1	1	1	1	4.687

Figure 16. Simplified schematic diagram of Gain Indicator circuit.

The gain control signals generated by the relay control circuits are binary in nature, that is, they are either 0 or +20v d-c. The four control signals are therefore converted to a coded analog signal by a binary-to-analog resistive network. The truth table, Figure 16, shows the relation between output voltage level and gain settings. The 4.12K resistor is equal to 2 bits connected to ground permanently, thereby dividing the 20v scale by 4.

The Gain Indicator data signal is monitored by the spacecraft on the subcommuted channel. The data is also useful in verifying receipt of gain setting ground command signals by the spacecraft.

In-Flight Calibration.

Figure 17 shows the simplified schematic diagram of the In-Flight Calibration (IFC) circuit.

The 1 pps and 10 pps timing signals from the spacecraft data system are utilized to develop the IFC signals. The inverters are buffer stages. The timing signal frequencies are scaled down by the Binary Scalers. Hence, the applied IFC signals are 0.5 cps and 5 cps square wave. These signals are summed by R13 and R14. C7 and C8 remove the d-c component of the IFC signal. R15, R16, and R17 determine the level of IFC signal corresponding to the Waveform Channel gain setting.

IFC signals are initiated via ground command link which eventually causes 50 msec. relay contact closures. One command signal turns IFC ON and another OFF. During IFC ON and OFF state, B+ for the Binary Scalers is turned ON and OFF, respectively. The attenuated IFC signal is applied to the sensor preamplifiers. During the OFF condition, the preamplifier calibrate input line is returned to ground through 600 ohms to minimize noise pick up and enables an external signal to be injected.

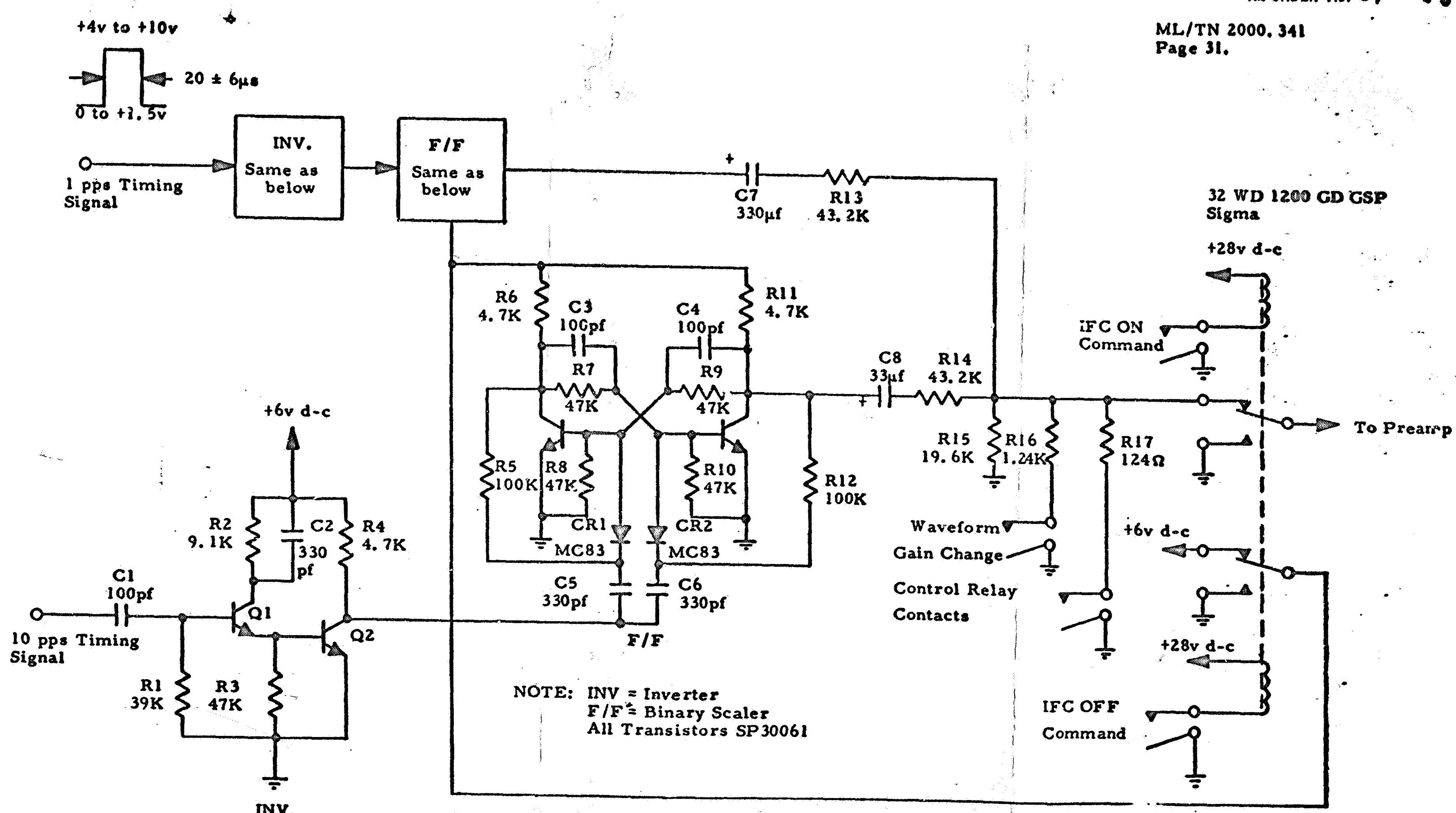


Figure 17. Simplified schematic diagram of IFC Circuit.

The 0.5 cps signal is used primarily to calibrate the Waveform Channel in narrow bandwidth state. The 5 cps signal is used to calibrate the Spectrum Channel. The calibrate signal, being a square wave, generates sufficient harmonics to calibrate all frequency bands of the Spectrum Channel.

Power Supply.

The power supply consists of a pre-regulator, a d-c to d-c converter, full wave rectifiers, a +20v and a +6v series voltage regulator. A simplified schematic diagram is shown in Figure 18.

The pre-regulator consists of a series voltage regulator that provides stable operating voltage to the d-c to d-c converter ensuring reliable operation. The circuit is relatively straight forward with CR1, a Zener diode, providing the reference voltage to Q3-Q4 differential amplifier which drives Q1 and Q2. Voltage divider R3 and R4 is selected to set the output voltage to +23.5v d-c. The collector voltage supply for Q2 and Q3 is provided by an isolated source which is higher than that for Q1. The higher potential allows Q1 to operate at a low collector voltage which minimizes power loss. Q1 is mounted on the housing for heat dissipation. The input filter, LI, CI, provides ripple filtering and minimizes turn-on surge current.

The d-c to d-c converter employs a saturating transformer push-pull oscillator that drives the power transformer. An additional winding is used on the oscillator transformer T1 to provide synchronization with the spacecraft synchronizing signal. The sync signal is transferred through a saturating amplifier which drives the sync winding and adds the necessary volt-seconds energy to force the oscillator to operate on frequency.

One series voltage regulator provides +20v d-c for the magnetometer

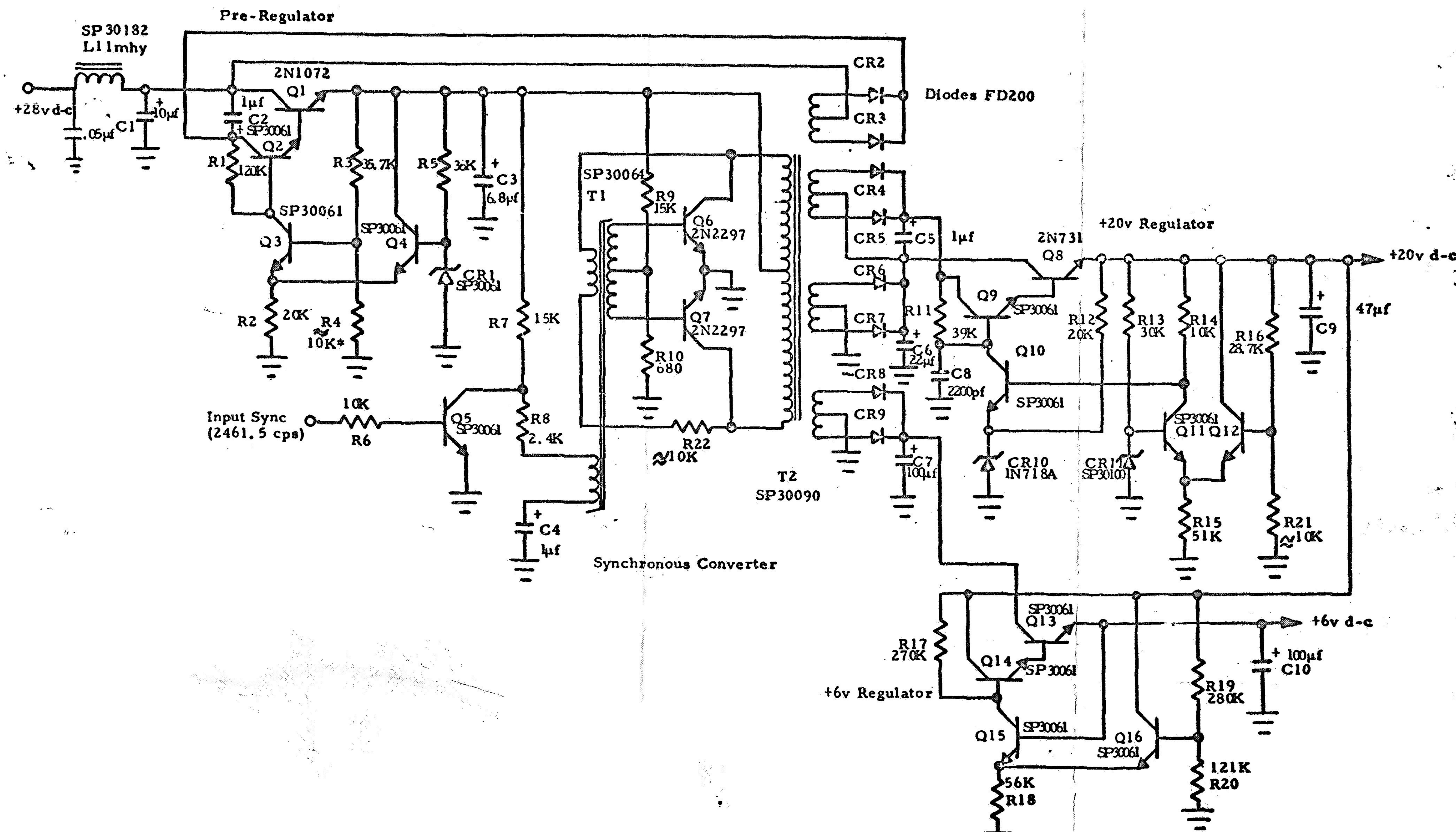


Figure 18. Simplified Schematic Diagram of Power Supply.

electronics. The reference voltage is derived from a Zener diode. Another regulator provides +6v d-c. The regulator +20v output is used as a reference for the +6v regulator.

Mechanical Design.

The principle design criteria of the Triaxial Search Coil Magnetometer was to minimize package weight. For this reason AZ313 magnesium tooling plate was used throughout the entire mechanical structure of the unit. The concept of welded cordwood type modules was employed for the same reason. Foam was used to add stiffness to the skin type mechanical structure and for increasing vibration damping characteristics of the component board assemblies.

The sensor assembly is contained in an aluminum housing with cover. The housing and cover are gold plated with the outside surfaces polished for required thermal properties. The search coil is installed into the housing and foamed which provides mechanical support for the sensor assembly. The cover is held in place by Armstrong 1156 adhesive coated on the entire inside surface of the cover. No mounting fasteners are used. The total assembly is mounted to spacecraft structure by clamps. Figure 19 shows a finished monoaxial sensor assembly. Three similar assemblies are used.

The preamplifier assembly is packaged in a housing with matching cover made of AZ31B magnesium tooling plate. The cover is fastened by four No. 4-40 screws. Spacecraft mounting provisions are provided by four No. 6-32 inserts located at each corner of the housing.

The three preamplifiers and one heater circuit are packaged into standard Marshall Laboratories V series soldered modules. The dimensions of the modules are 1.20" x 0.40" x 0.50". The four modules are then wrapped in a blanket of aluminized mylar to insure uniform

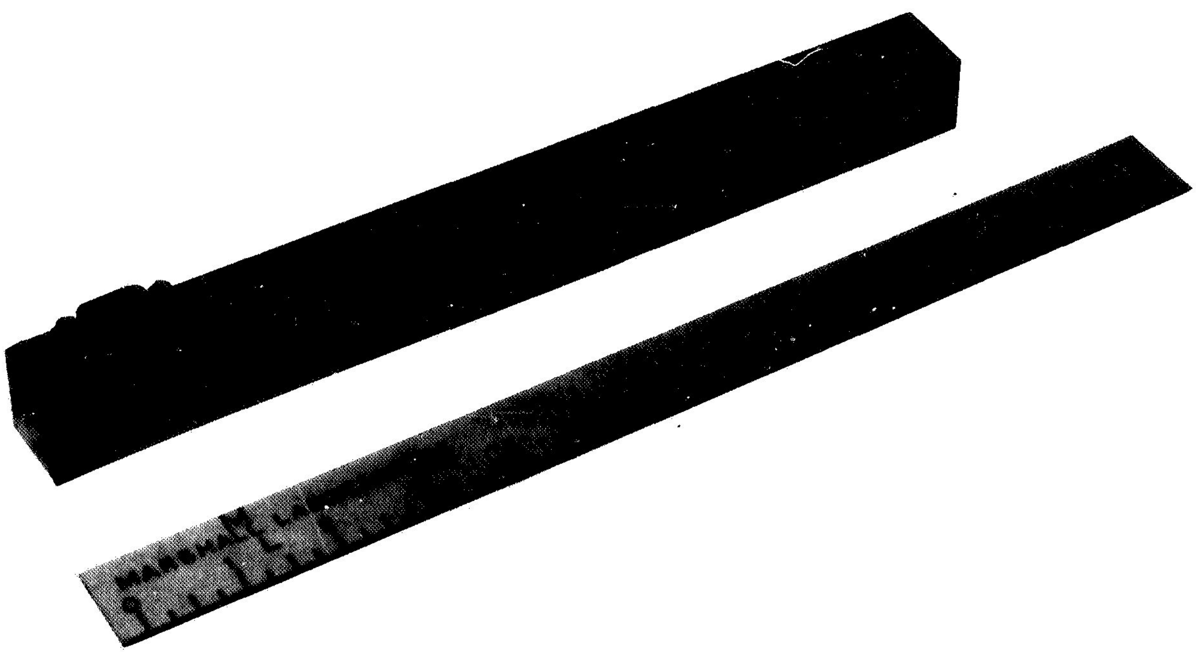


Figure 19. Monoaxial Search Coil Magnetometer Sensor, Model ML 157-1

ambient temperature and electrostatic shielding. The four modules are then foamed in the housing eith Eccofoam FPH which provides a rigid support for the modules within the housing. A completed pre-amplifier amplifier assembly is shown in Figure 20.

The main equipment package is assembled into two unique housings. One housing consists of the payload connector, test connector, integral RF cavity, one compartment for the power supply, and another compartment for the X axis magnetometer electronics. The other housing contains the magnetometer electronics for Y and Z axes. The two housings are designed to "plug together" to form one integrated package. The design incorporates the use of 0.031" thick, double sided printed circuit boards with plated-through holes. All conductor lines and pads on the circuit boards are solder plated for ease of soldering. Marshall Laboratories standard cordwood welded module construction is employed wherever possible throughout the unit. The modules are encapsulated in a high temperature epoxy. Completed board assemblies are bonded into the two housings with Epibond 1210 adhesive and secured with screws. After final checkout and calibration, the unit is foamed with Eccofoam FPH, a rigid, high temperature, polyurethane, foam-in-place resin. The unit is enclosed with covers for over-all electrostatic shielding and to prevent contamination from foreign substances. Figure 21 shows the main equipment package.

Summary of Specifications.

The following is a list of specifications for the EOGO Triaxial Search Coil Magnetometer.

1. Power Input
   a. Voltage: +23.5 to +33.5v d-c
   b. Current: 80 ma

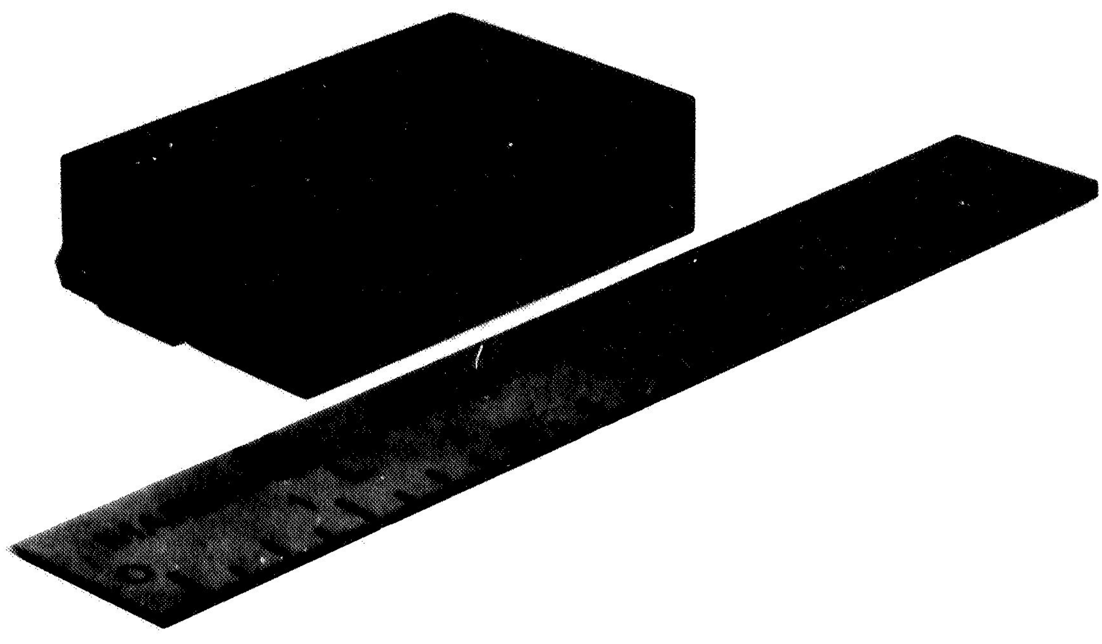


Figure 20. EOGO Search Coil Magnetometer Preamplifier Assembly, Model ML 150-1

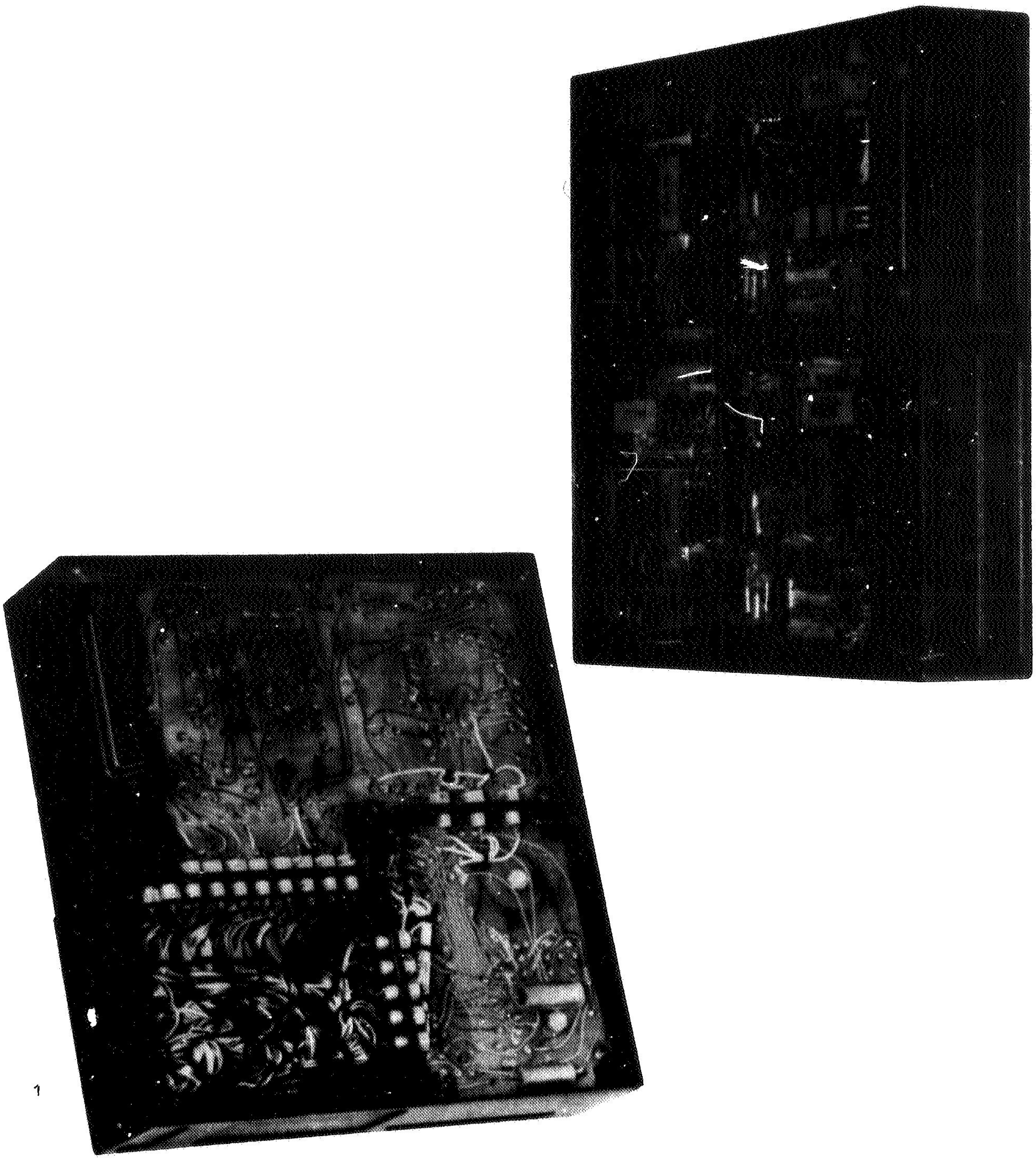


Figure 21. **EOGO Search Coil Magnetometer Main Equipment Package, Model ML 196-1**

2. Synchronizing Signal

a.	Frequency:	2461 cps ± 5%
b.	Amplitude:	4 to 7v p-p
c	Waveshape:	Squarewave.

3. IFC Timing Signals

a.	Frequency:	1 and 10 pps
b.	Quiescent level:	0 to + 1.5v
c.	Signal level:	+4 to +10v
d.	Waveshape:	Pulse
e.	Pulse width:	10 μ sec.

4. Command Signals

a.	Signal:	Relay contact closure to ground for 20 to 50 m sec.
b.	Types:	IFC ON, IFC OFF, Waveform HI Gain, Waveform MED Gain, Waveform LO Gain, Spectrum HI Gain, Spectrum MED Gain, and Spectrum LO Gain

5. Mode Signal

a.	0 to + .6v d-c:	corresponds to group 1 record and group 2 real time.
b.	+3.9 to +9v d-c:	corresponds to group 2 record and group 1 real time.

6. Bit Rate Signal

a.	+3.3v d-c ±5%:	corresponds to 1K bps.
b.	+5.1v d-c ±5%:	corresponds to 8K bps.
c.	+7.5v d-c ±5%:	corresponds to 64K bps.

7. Switch Signal

a.	0 to +2v d-c:	corresponds to group 1 real time transmission.
b.	+7 to +33.5v d-c:	corresponds to group 2 real time transmission.

8. Search Coil

a.	Sensitivity:	8 μv/γ-cps nominal
b.	Resonant frequency:	700 cps nominal

9. Preamplifier

a.	Gain:	110 nominal
b.	Controll temperature:	$20 \pm 5^{\circ}C$
c.	Noise level:	< 1 μv

10. Frequency Rejection

a.	Rejection:	>50 db at 400 cps
b.	Insertion loss:	3 db

11. Spectrum Channel

a.	Gain:	2, 20, or 200 (controlled by ground command)
b.	Pass bands:	10, 32, 100, 320, and 1000 cps
c.	Q:	3.3
d.	Output signal:	0 to +5v where zero corresponds to quiescent condition.
e.	Response Time Constant:	0.2 sec. for increasing signals, 40 sec. for decreasing signals.
f.	Output impedance:	< 1000 Ω

12. Waveform Channel

a.	Gain:	10, 100, or 1000 (controlled by ground command)
b.	Narrow band:	.01 to 1 cps when data transmission is at 1000 or 8000 bps.
c.	Wide band:	.01 to 64 cps when group 1 or 2 is transmitted in real time at 64K bps.
d.	Output signal:	+2.5v d-c corresponds to zero field condition. 5v p-p corresponds to full scale voltage.
e.	Output impedance:	< 1000 Ω.

13. Gain State Output
    a. Voltage range: 0 to 4.7v d-c
    b. Gain states: See Figure 16, page 29.

14. Temperature
    a. Operating: +5°C to +35°C
    b. Storage: -37°C to +60°C
    c. Calibration: -5°C to +45°C

15. Weight
    a. Search coil: .49 lbs per axis
    b. Preamplifier: 2.750" x .675" x 1.750"
    c. Main experiment package: 3.062" x 6.750" x 7.250"

BENCH TEST EQUIPMENT DESCRIPTION

The purpose of the Bench Test Equipment (BTE) is to allow check-out and calibration of flight magnetometers. It supplies operating power for the magnetometer and its internal circuits, simulates all spacecraft signals, monitors data signals and pertinent test signals, provides calibration signals and includes a fluxtank (magnetic shield) with calibration solenoid and associated electronics. The total unit is fabricated in a suitcase for compactness and portability. Details of the BTE is discussed in the following sections.

System Description.

Figure 22 shows the functional block diagram of the BTE. Four main groups of circuits are required. These groups are a power supply unit, monitor circuits, spacecraft signal simulators, and calibration system.

The power supply provides primary voltage (+28v d-c nominal) for operation of the experiment. The voltage is adjustable, in steps, over the range of 23v to 33v to allow performance testing of the experiment power supply. A battery charger, used to charge the batteries, is included in the BTE which allows about five (5) hours continuous operation after overnight charging.

The monitoring circuits measure spacecraft interface signals, monitor power supply voltages, and indicate converter synchronism. The monitor circuits consist of a-c and d-c transistorized voltmeters. The d-c voltmeter measures Spectrum Channel data outputs, Waveform Channel zero bias levels, gain indicator output voltage, and preamp output d-c voltage levels. Measurement range is adjustable from 0. 1v full scale to 10v full scale. An electrical zero adjustment of the meter is provided to compensate for battery voltage variations. The a-c meter measures preamp and waveform outputs. Full scale measurement range of the meter is 0. 3v rms to 3v rms. The power supply monitor indicates voltage deviations, from nominal, of the pre-regulator, the 20 volt regulator, and the 6 volt regulator outputs. Full scale deviation ranges are 1. 1v, 0. 5v, and 0. 25v. The sync detector compares the converter signal with the sync signal and indicates frequency difference over a wide range.

Three types of spacecraft signals are simulated by the BTE. One type is 50 m sec. relay contact closures to operate gain change amplifiers in the spectrum and waveform and to command IFC circuits. These signals must be independently controlled. Another type of signal is timing

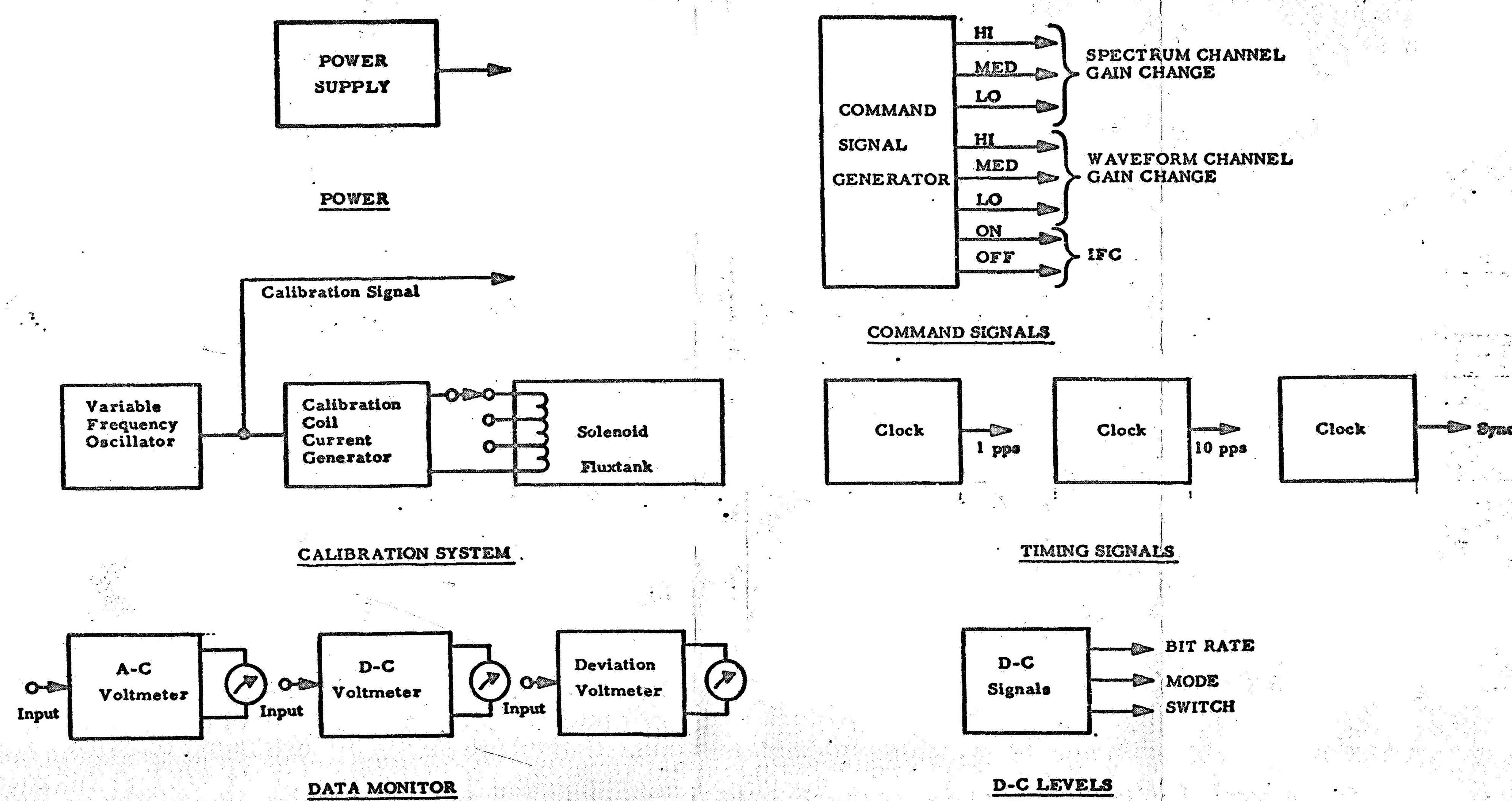


Figure 22. Functional Block Diagram of BTE.

signals. The 1 pps and 10 pps signals are generated to operate the IFC circuit. A 2461.5 pps sync signal is also generated to synchronize the experiment d-c to d-c converter. The last type of signals are d-c voltage levels that simulate the MODE, SWITCH, and BIT RATE conditions.

Calibration a-c signals are provided by the BTE to allow checkout of the total system without the sensor. This signal is applied to the main experiment package and used to calibrate the Spectrum and Waveform Channels. Signals of 1 cps, 3.2 cps, 10 cps, 32 cps, 100 cps, 320 cps, 1000 cps, and 3200 cps, whose frequency is variable over ± 10% of nominal value and amplitude is variable in three levels, are provided. To test the sensor, a magnetically quiet environment is required. The fluxtank provides this test volume. A calibration solenoid (internal to the fluxtank) is used to generate three levels (high, medium and low) of calibration magnetic fields which drives the magnetometer into the center of measurement range (high, medium, or low) under test.

The total unit schematic diagram can be found in Marshall Laboratories Drawing 50354. This drawing is not included because of its relatively large size. However, details of the various circuits are discussed below with associated simplified schematic diagrams.

<u>Power Supply.</u>

Figure 23 shows the BTE power supply. Primary power is provided by five NiCd batteries. Switch S1 is used to select either +22.8v, +27.6v, +32.4v or 0v to operate the flight magnetometer. This selection allows performance testing of the magnetometer power supply unit.

Switch S2 controls power to the BTE internal circuits and battery charger which consists of CR1, R1, and T1. The charging current is a half wave rectified 60 cps current derived from power line. R1 limits charge current to 60 ma.

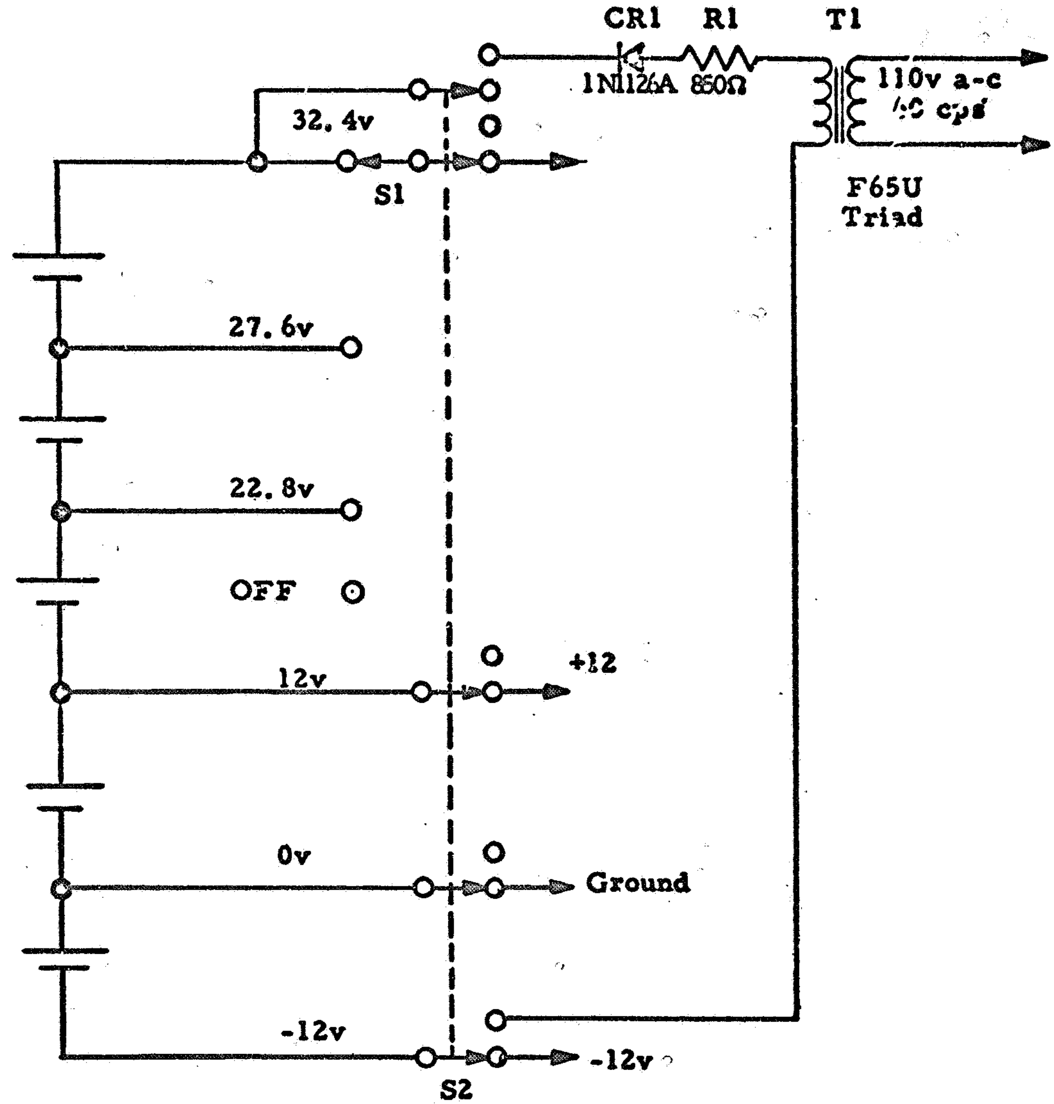


Figure 23. Simplified Schematic Diagram of BTE Power Supply.

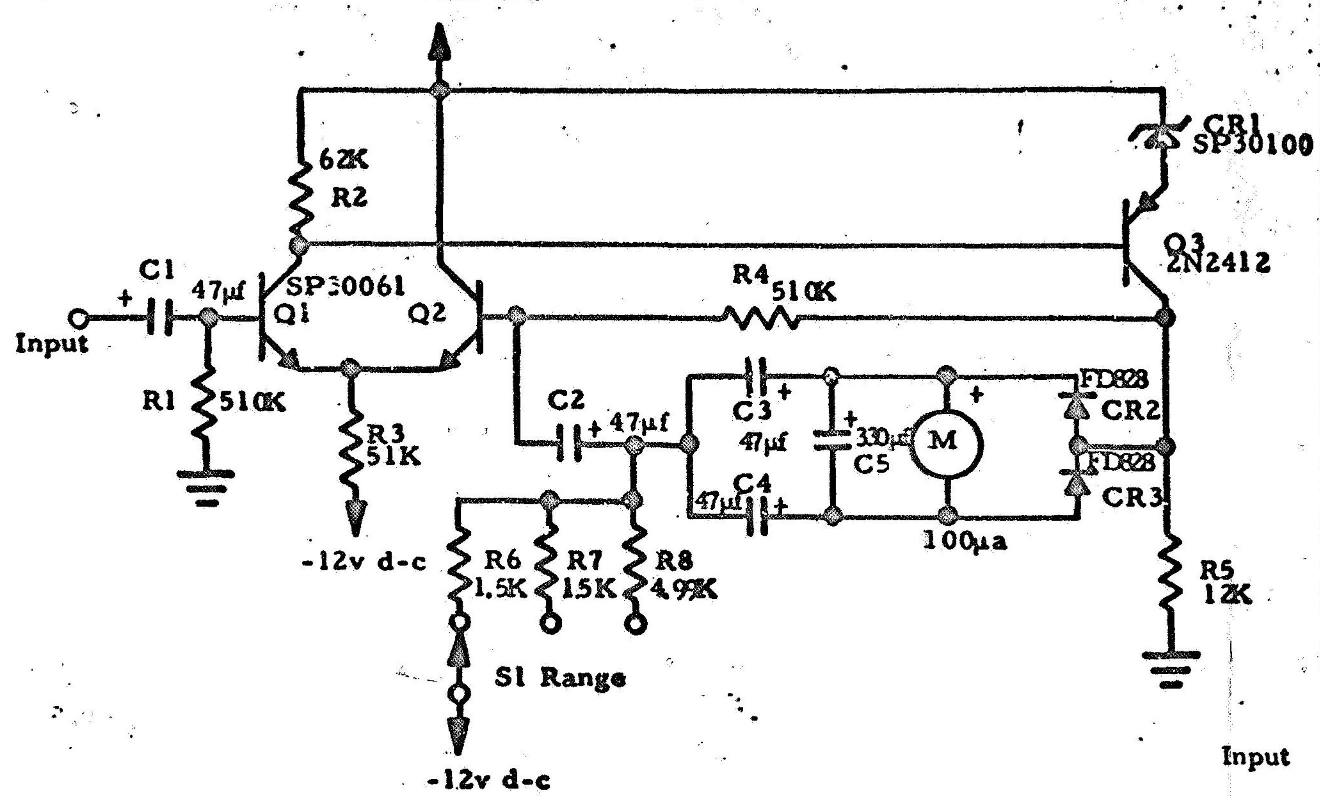
Data Monitor.

Three basic meters are used to monitor all pertinent signals. An a-c voltmeter is used to measure Waveform Channel and preamplifier output signals. A d-c voltmeter is used to measure Spectrum Channel outputs, Waveform Channel zero field bias level, and Gain Indicator output.

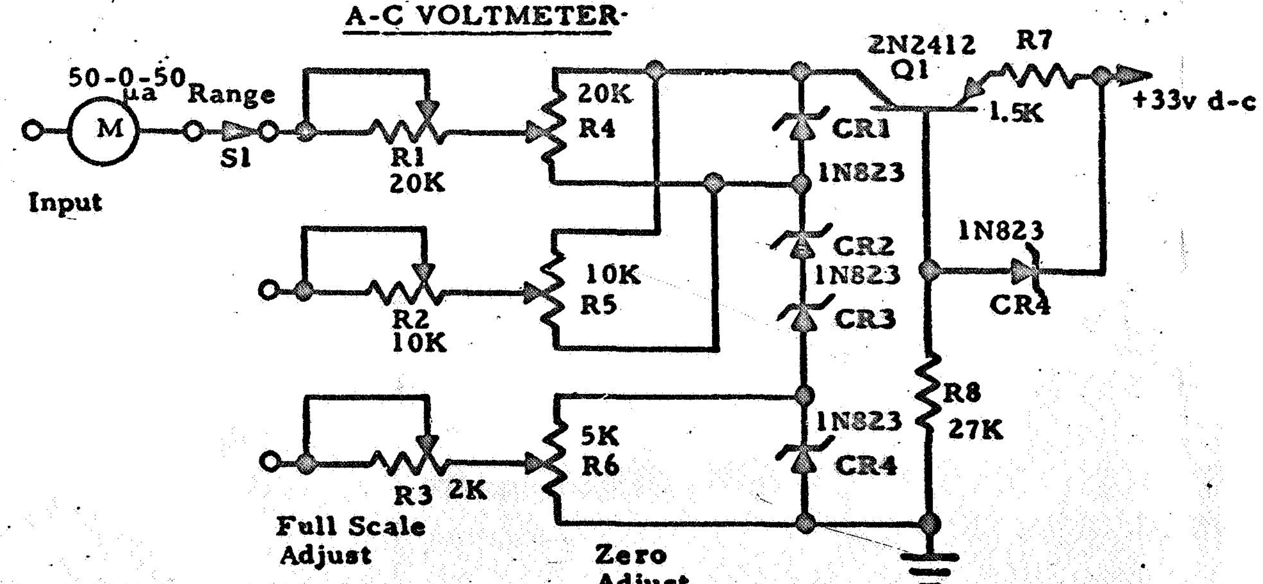
A deviation d-c voltmeter is used for precise measurement of regulator output voltages. The function to be measured is selected by front panel selector switches. Figure 24 shows the three voltmeter circuits.

The a-c voltmeter consists of a two-stage amplifier with a bridge rectifier in the feedback loop. Transistors Q1 and Q2 are connected as a differential amplifier to enhance d-c stability. R4 provides d-c feedback from the output of Q3 whereas the bridge-meter network provides a-c feedback. Measurement range is determined by selection of R6, R7, or R8 with S1. The resistors set the amount of feedback, thereby setting the closed loop gain. The values of R6, R7 and R8 are selected for full scale measurement range of 0.3v rms, 1v rms, or 3v rms.

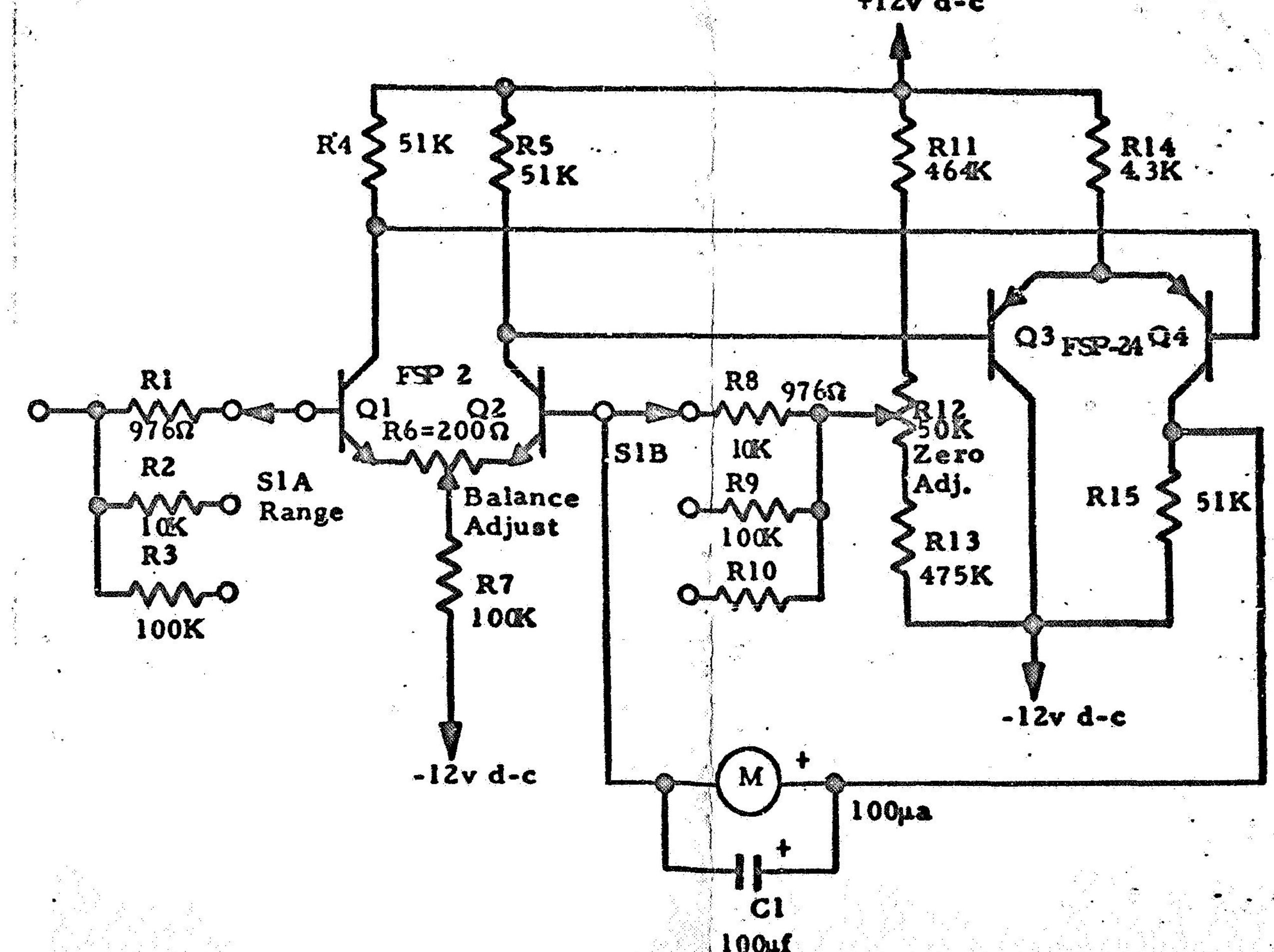
The d-c voltmeter consists of two differential amplifier stages with a microammeter providing d-c feedback path. The input stage transistors (Q1 and Q2) are mounted in a single can to minimize drift due to ambient temperature variations. One degree Centigrade change can cause an equivalent input drift of 3 millivolts. Matching of the transistor pair is accomplished by adjustment of the balance potentiometer R6. The zero adjustment potentiometer R12 is set for null with the input floating. The effect of the bias network is to make the input impedance of the meter appear entirely resistive. The current feedback makes the microammeter reading independent of the resistance of the microammeter. Capacitor C1 provides damping for the meter movement. Three feedback resistors



A-C VOLTMETER



DEVIATION METER



D-C VOLTMETER

Figure 24. Data Monitor Meter Circuits

(R8, R9 and R10) provide full scale measurement ranges of 0.1, 1.0, and 10.0 volts. Additional resistors in series with the input base (R1, R2, and R3) provide compensation for the base current of the feedback transistor.

The deviation voltmeter compares the output voltage of the magnetometer regulators with an accurate reference voltage and indicates deviation of voltage from nominal value. The reference voltage is derived from stable Zener diodes. To insure stability of the reference voltage, the Zener diodes are driven by a constant current source (Q1) which minimizes drift caused by BTE battery voltage variations. Potentiometers R4, R5, and R6 allow exact setting of reference voltage, and potentiometers R1, R2, and R3 set sensitivity of the Galvanometer.

Spacecraft Signals.

Figure 25 shows the ground command signal generator circuit. One signal generator is used to generate all command signals. The command is initiated by switching either S1 (Spectrum Channel gain setting), S2 (Waveform Channel gain setting), or S3 (IFC) to the desired position. With the switches in series, command signals can be independently initiated. When the switch wiper arm breaks and makes contact, a trigger pulse is generated which triggers the monostable multivibrator (Q1 and Q2). The time constant R6 C2 is set to provide 100 millisecond delay which is sufficient time to allow switch contact bounce to subside. The ganged output switch is simultaneously switched to the desired command input line. The 100 millisecond delay provides enough time for the output switch to make firm contact before the command signal is generated. The falling edge of the input multivibrator signal triggers the output monostable multivibrator (Q3 and Q4). The time constant R13 C5 is set for 50 millisecond delay which is the required relay contact closure time. The output multivibrator signal drives relay driver Q5 and the ground command contact closure is simulated.

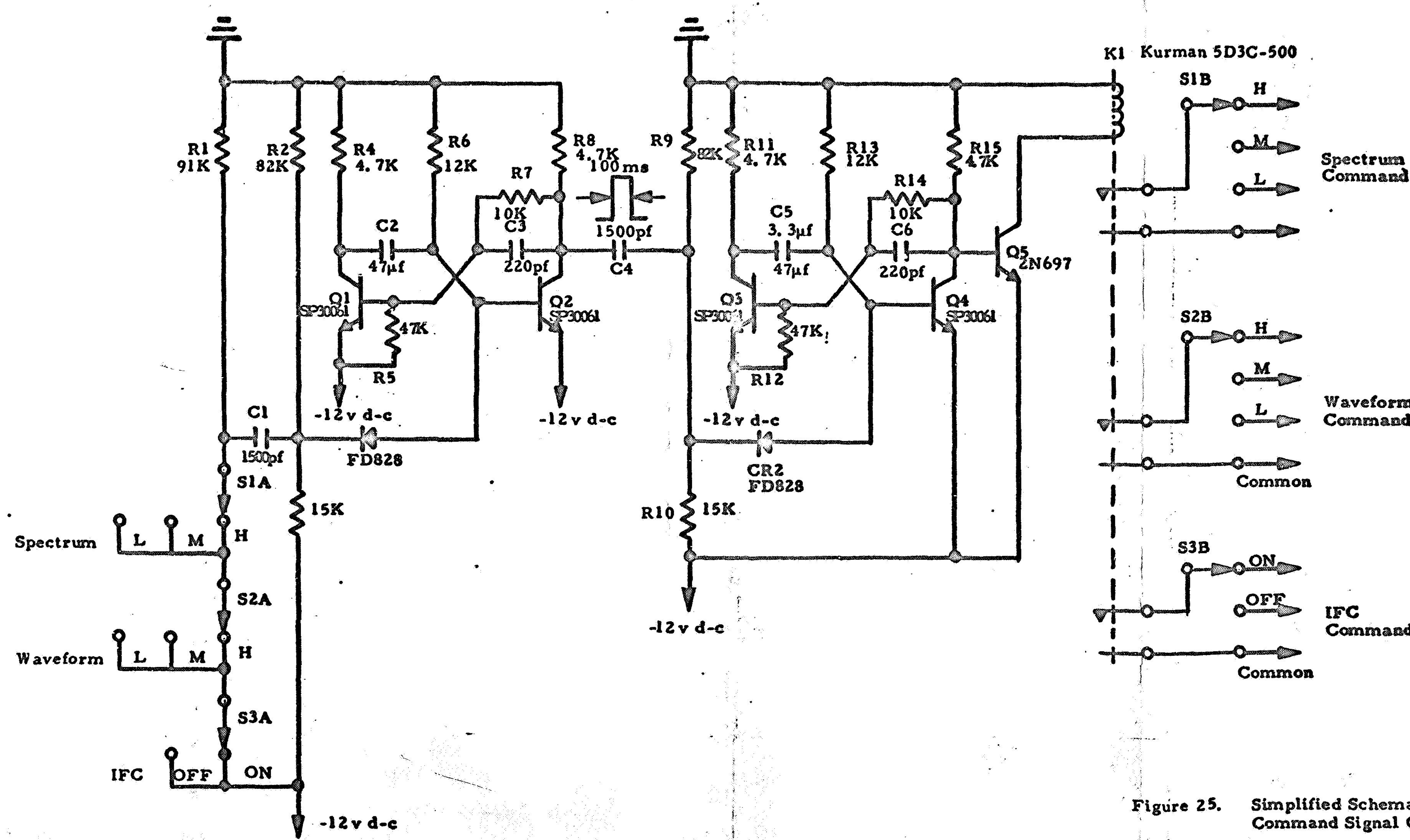
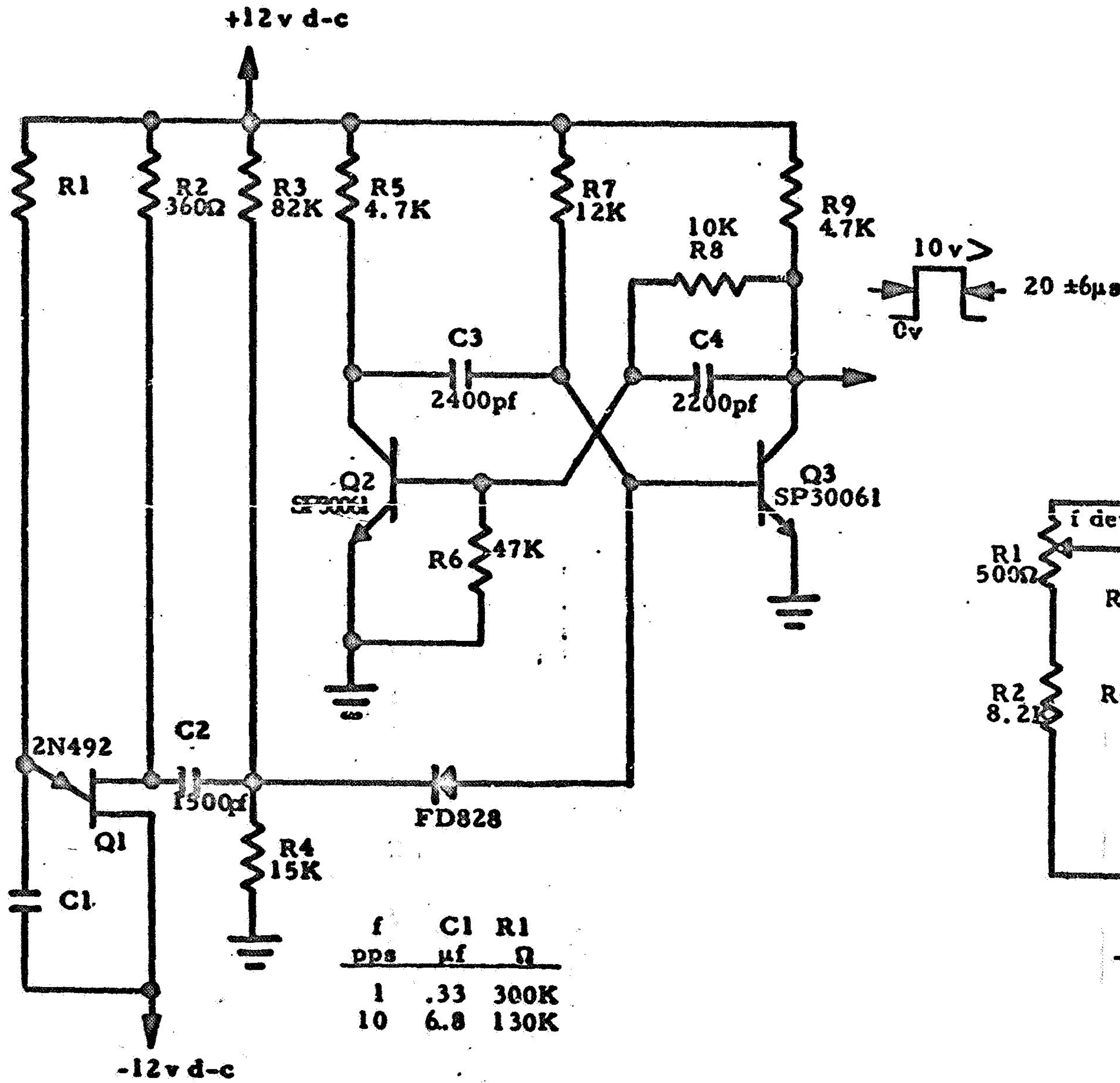


Figure 25. Simplified Schematic of Ground Command Signal Generator.

Figure 26 shows timing signal generator circuits. The 1 pps and 10 pps IFC signals are generated by similar circuits. The basic clock consists of a unijunction transistor (Q1) relaxation oscillator. Operating frequency is determined by R1C1 time constant. The output of Q1 triggers the monostable multivibrator (Q2 and Q3) whose delay is set for about 20 μseconds by R7C3 time constant. The IFC output signal is then a 0 to + 10v square wave pulse whose width is 20 μseconds.

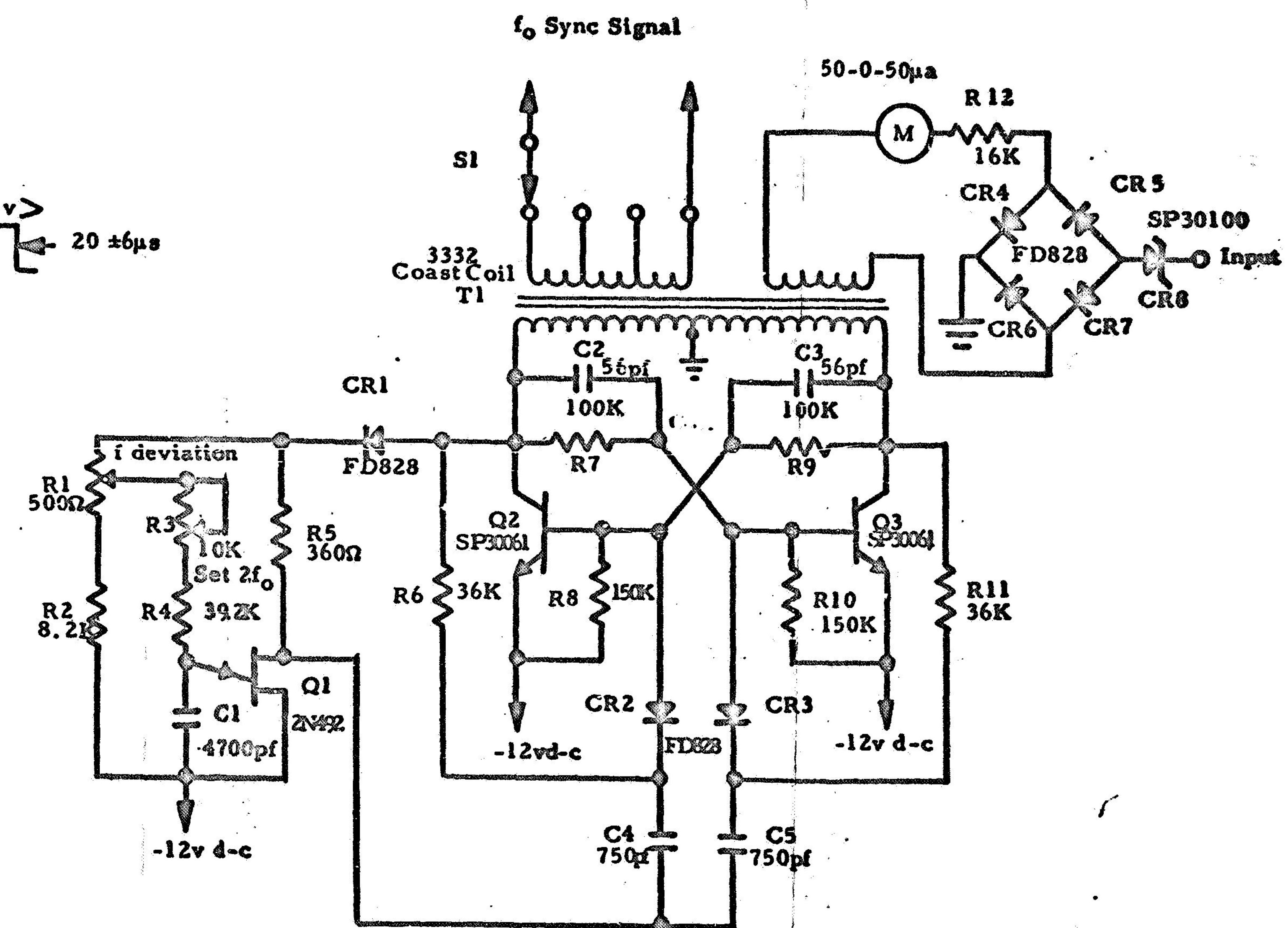
The sync signal required to test synchronizing ability of the magnetometer converter unit is generated by a clock and binary scaler. The clock consists of a unijunction transistor (Q1) relaxation oscillator. Nominal operating frequency (4923 cps) is set by (R3 + R4) C1 time constant. R1 provides about ± 10% frequency variation control. The fundamental frequency is divided by two (2461.5 cps) by the transformer coupled binary scaler (Q2 and Q3). The secondary winding of T1 provides 4, 6, and 7v p-p taps. Switch S1 selects these voltages and allows performance test of the converter unit as a function of sync signal amplitude. An additional winding is used to provide a reference signal for the phase sensitive detector circuit. The reference signal is compared with a test signal brought out from the magnetometer converter. Phase comparison is performed by rectifier bridge CR4, CR5, CR6, CR7, and isolation diode CR8. The bridge is driven into conduction on alternate half cycles by the input signal. If the reference signal polarity is negative during this period, the meter deflects to the left. If the polarity is positive, the meter deflects to the right. Null of the meter occurs when phase difference is 90°. Hence, when the converter is synchronized, the meter indicates either plus or minus deflection. Deflection between these limits is proportional to phase difference. The scale is not calibrated. The meter used for this monitoring function is the deviation null meter which is switched in the circuit by the operator.

Figure 27 shows circuits that generate the BIT RATE, MODE, and SWITCH signals to test the Waveform Channel bandwidth control circuits.



f pps	C1 μf	R1 Ω
1	.33	300K
10	6.8	130K

IFC Timing Signal Generator



Sync Signal Generator and Monitor

Figure 26. Simplified Schematic Diagram of Timing Signal Generator Circuits.

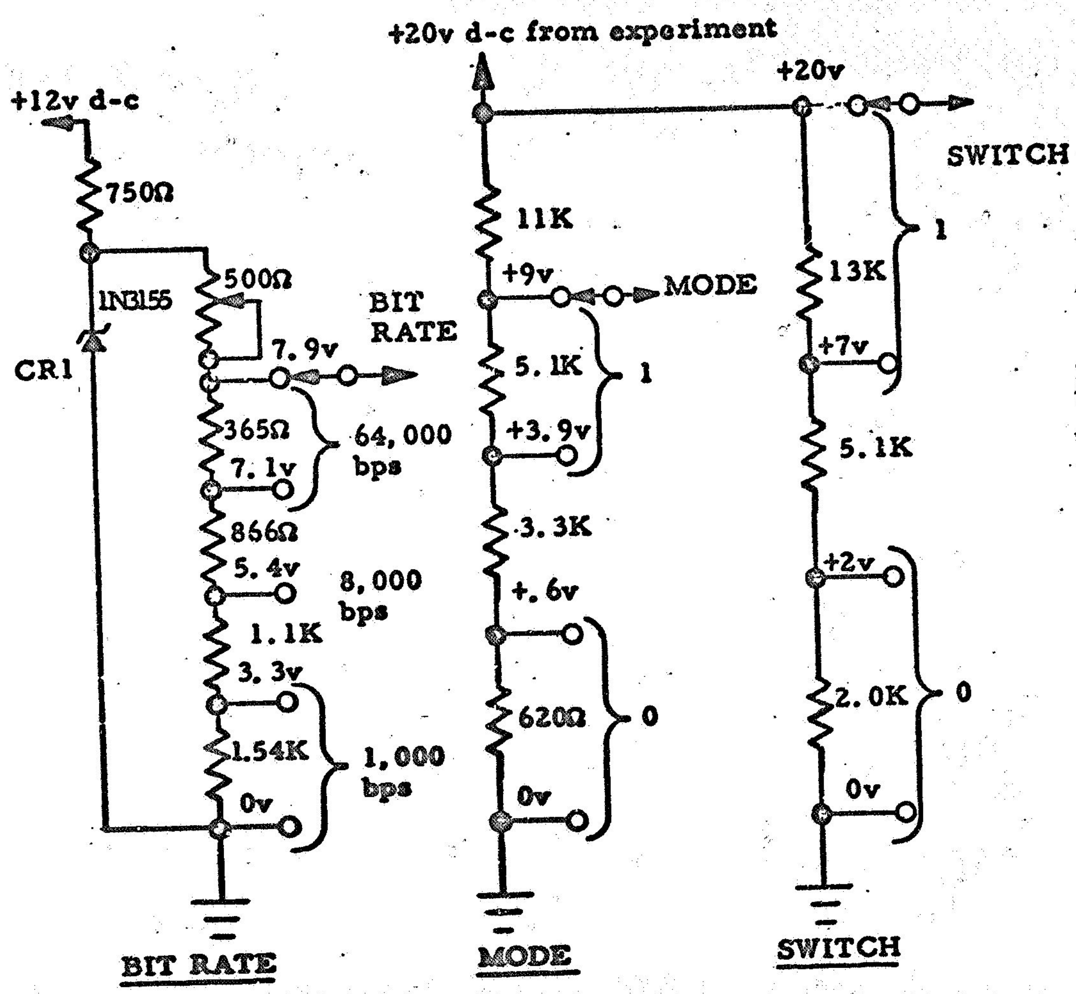


Figure 27. Waveform Channel Bandwidth Control Signal Generator Circuits

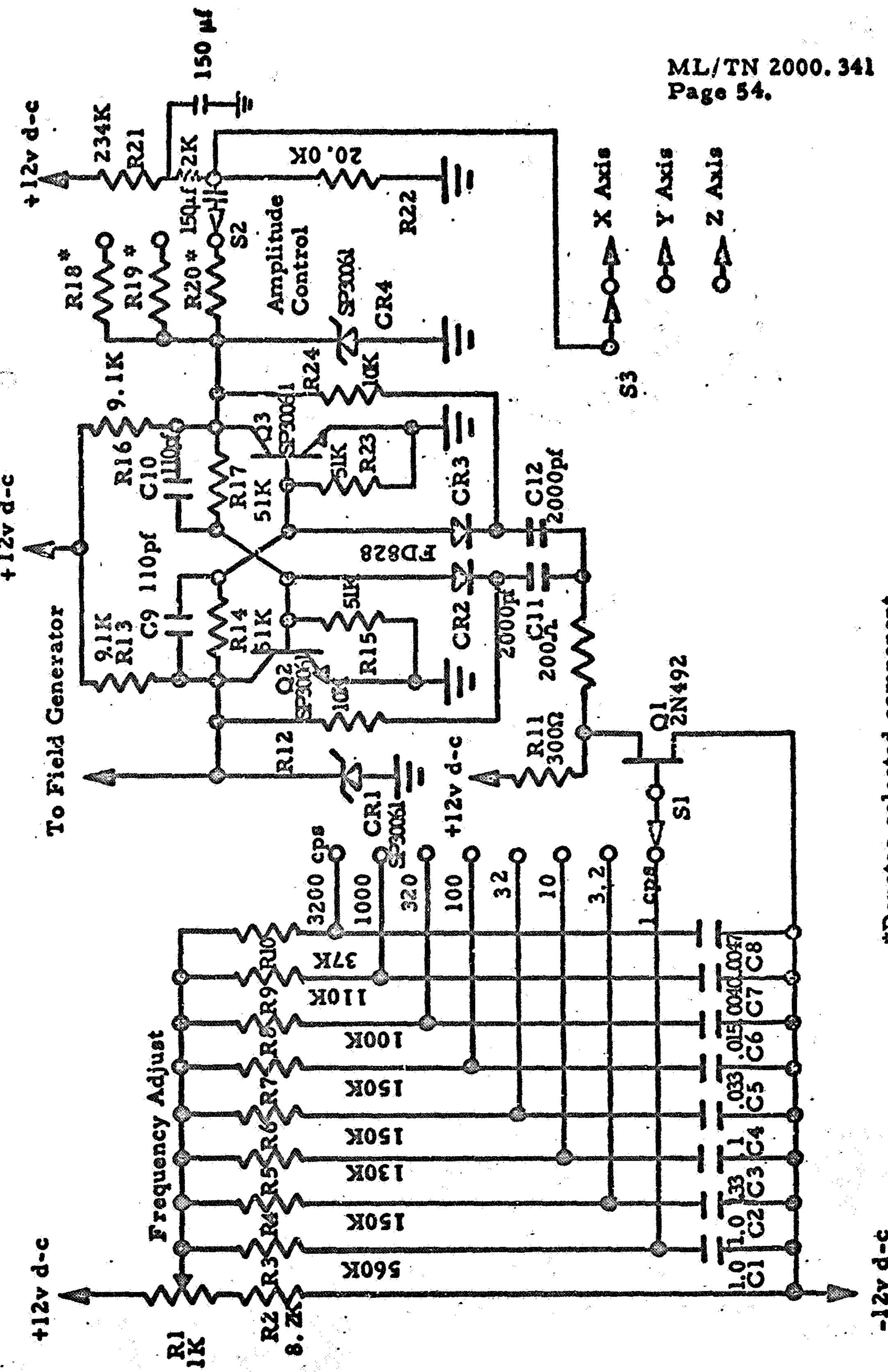
All signals are d-c voltages. Output selector switches provides selection of appropriate signal voltages within specified limits. The BIT RATE signal is derived from Zener diode CR1 whereas the MODE and SWITCH signals are derived from the magnetometer +20v regulator output. Resistor divider networks provide appropriate voltage taps, as shown in the schematic diagram, for the output selector switches.

Calibration System.

A-C signals are provided by the BTE to calibrate the Spectrum and Waveform Channels. Figure 28 shows the simplified schematic diagram. The signal generator circuit basically consists of a unijunction relaxation oscillator driving a binary scaler. The clock frequency is controlled by selecting the desired RC time constant with S1. Fine frequency adjustments are accomplished by R1 which controls the d-c voltage applied to the RC network. The clock is followed by a toggling bistable multivibrator (Q2 and Q3) which converts the clock pulses to a square wave signal at half clock frequency. Both outputs of the multivibrator is clipped by Zener diodes, CR1 and CR4, attenuated by a variable voltage divider, and summed with a d-c voltage to simulate the search coil preamplifier output signal. Signal levels are .005v to .5v at 1, 3.2, 10, 32, 100, 320, 1000, or 3200 cps. This calibration signal is applied to the input of the magnetometer Band Reject Filter which drives the Spectrum and Waveform Channel.

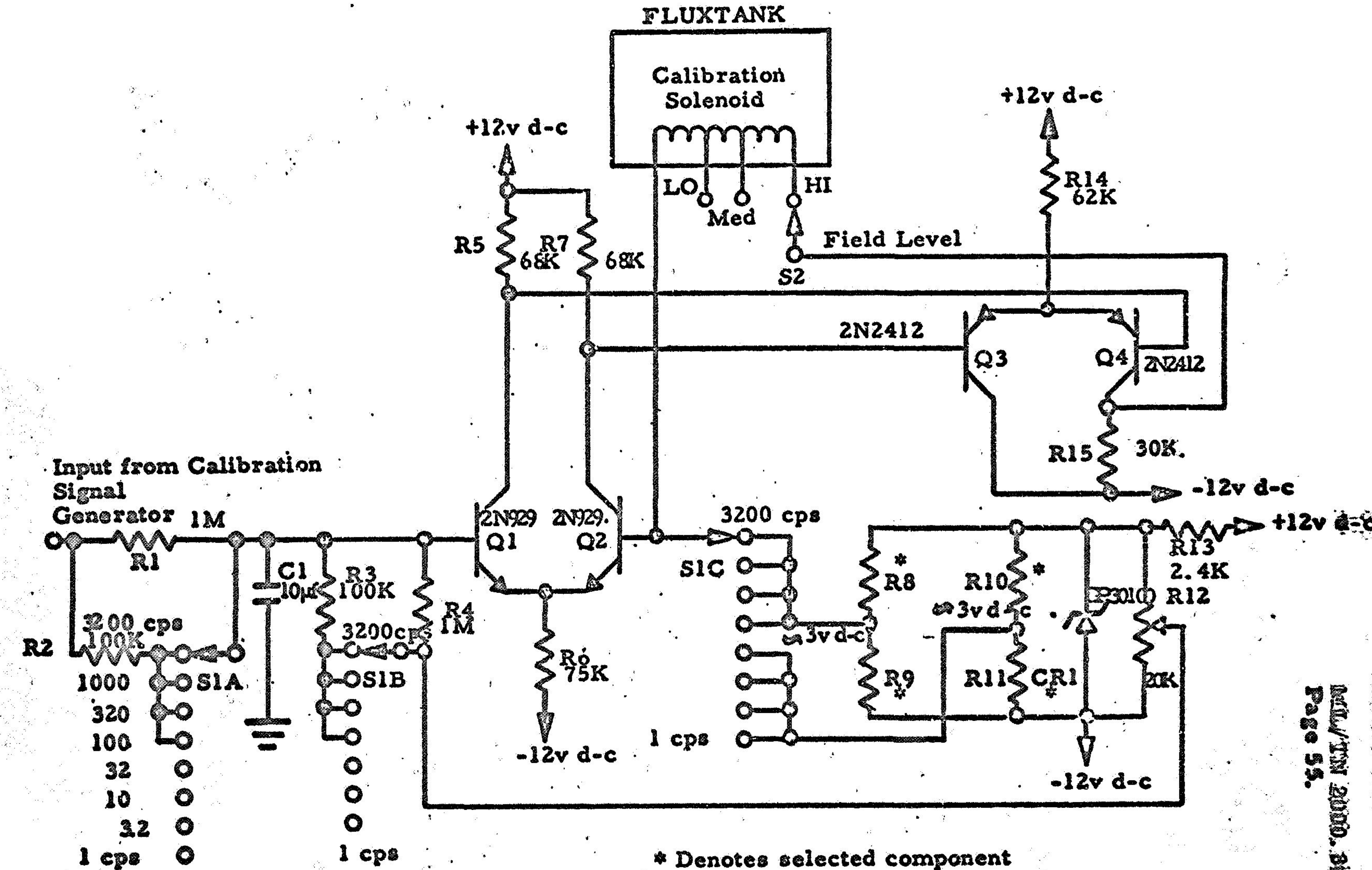
The complementary signal of the multivibrator is applied to the magnetic field generator circuit shown in Figure 29. The square wave signal is integrated by R1, R2, and C1 network. The output of the integrator is a triangular wave whose amplitude is inversely proportional to frequency. The triangular voltage serves as the input signal to the four transistor direct coupled double differential amplifier (Q1, Q2, Q3, and Q4). This type of amplifier is chosen for its excellent d-c stability. The d-c

RE-ORDER No.



*Denotes selected component

Figure 28. Calibration Signal Generator Circuit.



* Denotes selected component

Figure 29. Simplified Schematic Diagram of Magnetic Field Generator.

amplifier gain is controlled by current feedback through the solenoid winding of the fluxtank, thereby making the field in the fluxtank a triangular wave whose amplitude is inversely proportional to frequency and is independent of coil impedance. It is necessary to have two integrators and two sets of feedback resistors for low and high frequencies. The switching is done by S1 which is actually ganged with the frequency selector switch of the calibration signal generator. R2 is disconnected for signal frequencies between 1 through 30 cps to compensate for integration time constants. Field level is controlled by selecting the desired tap on the solenoid coil by S2 which is ganged with the amplitude control of the calibration signal generator.

Mechanical Design.

The BTE is packaged into a standard Halliburton aluminum carrying case as shown in Figure 30. The electronics is mounted onto two solder plated printed circuit boards. Switches and meters are mounted on a hinged front panel assembly. The board assemblies and the back of the front panel are accessible for rework and trouble shooting by folding back the front panel.

A compartment is provided in the case lid for storing cables and miscellaneous items. A test adapter is also mounted inside the lid which can be inserted in the test setup for the monitoring of signals by additional test equipment.

The fluxtank is designed to provide a "field-free" test volume to test and calibrate the Triaxial Search Coil Magnetometer. The fluxtank is composed of four concentric cylinders; the outer cylinder is fabricated from aluminum and the remainder out of mu-metal. The mu-metal cylinders provide magnetic field attenuation with relatively high permeability characteristics while the outer aluminum cylinder provides structural support with minimum weight. The cylinders are completely enclosed by two lid assemblies

Figure 30. **Search Coil Magnetometer Checkout Unit, Model ML 145-1.**

designed for providing minimum magnetic leakage. A special shock mounted carriage assembly secures the portable fluxtank when being transported. The fluxtank can be used while in the suitcase or it can be removed for portable use.

The solenoid calibration coil, fabricated from Plexiglass, fits into the inner cylinder of the fluxtank. The search coil sensor is inserted into the solenoid coil and connectors provide electrical signal continuity. Coil constant is nominally 1.5 $\gamma/\mu a$.

GROUND SUPPORT EQUIPMENT

The purpose of the Ground Support Equipment (GSE) is to perform go-no-go tests of the magnetometer during payload system tests. The GSE provides spacecraft command signals, monitors power supply voltages, and monitors instrument data outputs. These functions are performed by three basic circuits described below. Power to operate the GSE circuits is provided by batteries.

Command Signal Generator.

The command signal generator provides the following command signals.

1. IFC - ON
2. IFC - OFF
3. WAVEFORM GAIN - LOW
4. WAVEFORM GAIN - MEDIUM
5. WAVEFORM GAIN - HIGH
6. SPECTRUM GAIN - LOW
7. SPECTRUM GAIN - MEDIUM
8. SPECTRUM GAIN - HIGH

The circuit is similar to that used in the BTE which was discussed in a previous section. That is, the command switch initiates a pulse that triggers two stages of monostable multivibrators whose output drives a relay driver. The relay 50 m sec contact closure is switched to appropriate input lines.

Power Supply Monitor.

The power supply monitor consists of a d-c deviation voltmeter used to measure the magnetometer power supply voltages and the BTE battery voltage. Figure 31 shows the deviation voltmeter circuit. The measured voltage is compared with a Zener diode reference voltage. The following signals can be measured.

	Input	Null Voltage	Full Scale Voltage
1.	GSE Battery Voltage	13v	Positive deflection indicates good batteries.
2.	Magnetometer Input Regulator	23.5v	± 1v
3.	Magnetometer Output Regulator	20v	± 0.5v
4.	Magnetometer Output Regulator	6v	± 0.5v

S1 is a multi-deck switch that selects the input voltage to be measured.

Meter Circuit.

The meter circuit is used to monitor a-c or d-c voltages. Figure 32 shows a simplified schematic diagram. The following signals are monitored.

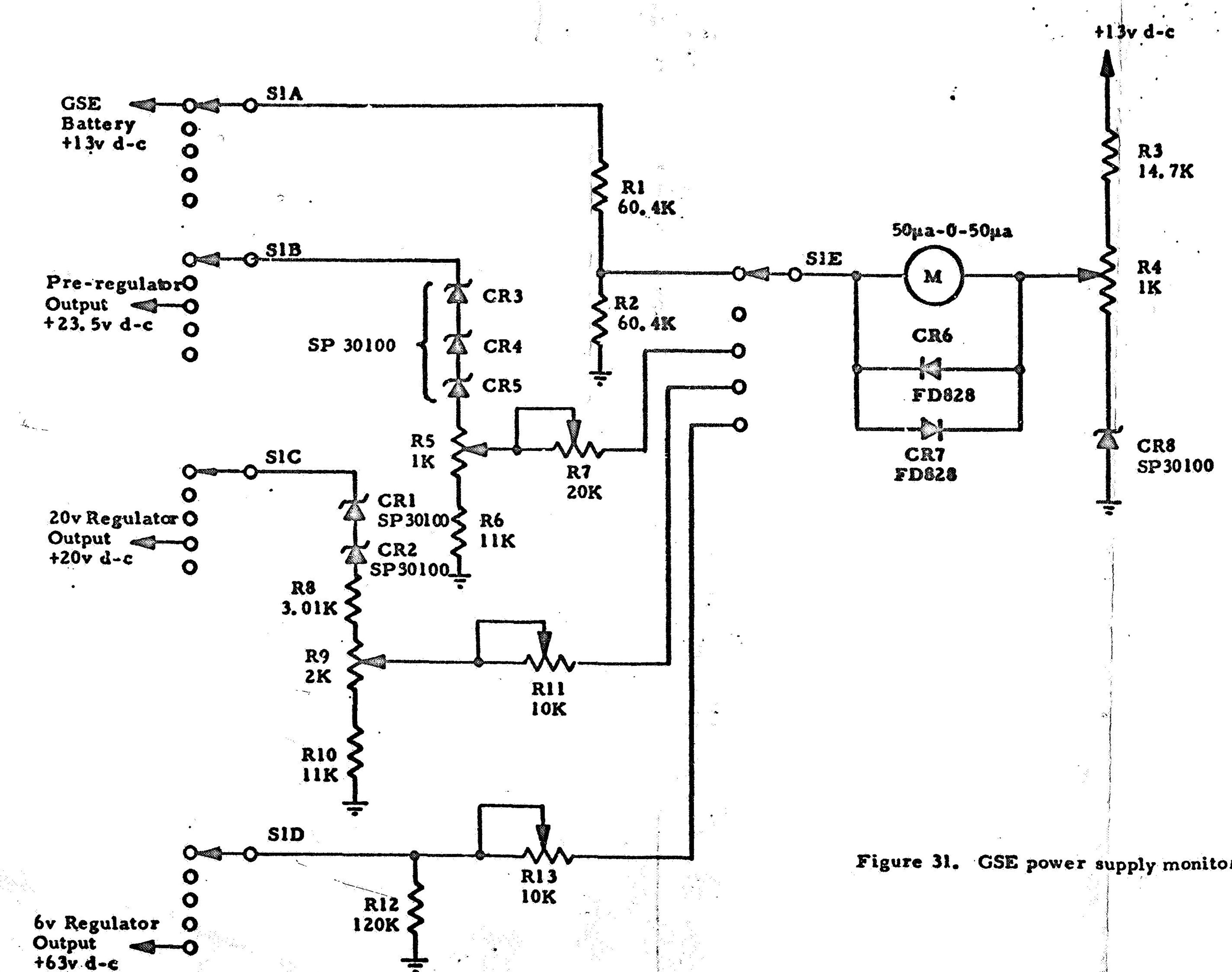


Figure 31. GSE power supply monitor circuit.

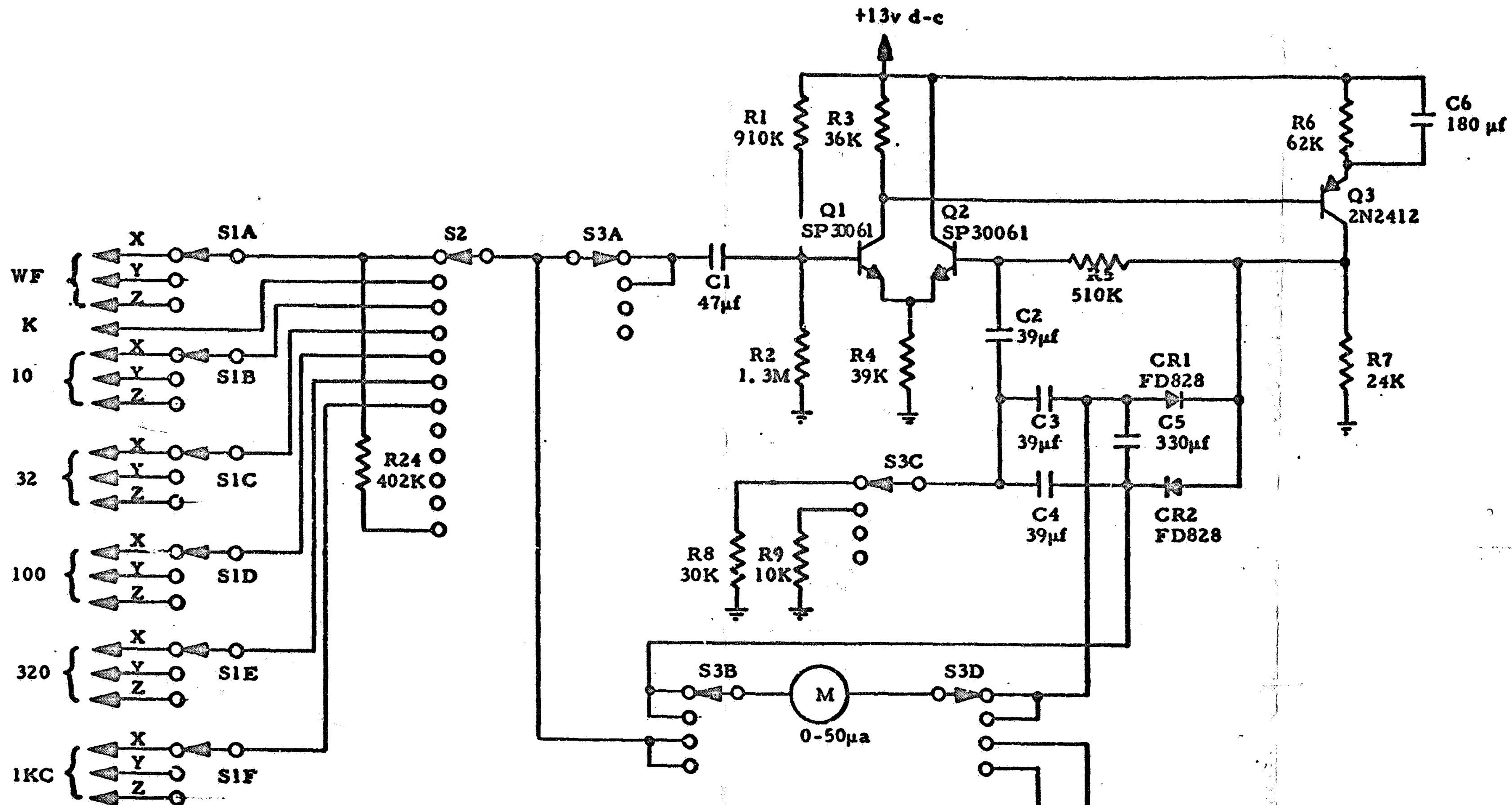


Figure 32. GSE meter circuit.

1. Preamplifier output d-c voltage.
2. Waveform output voltage.
3. Scale indicator output voltage.
4. 10 cps spectrum output voltage.
5. 32 cps spectrum output voltage.
6. 100 cps spectrum output voltage.
7. 320 cps spectrum output voltage.
8. 1000 cps spectrum output voltage.

Switch S1 is used to select either X, Y, or Z axis signal. Switch S2 selects the data to be monitored. One meter movement is used to measure either a-c or d-c voltages. Switch S3 is used to switch either the d-c or a-c voltmeter circuit and to change measurement range. A special cable is provided to measure preamplifier output voltages. The cable meets the preamplifier output to the Waveform output terminals.

For the measurement of d-c voltages, the microammeter is used directly. Current limiting resistors R10 and R11 sets full scale measurement range to 3v or 10v. Resistor R24 sets the full scale to 30v for use with the preamplifier output level monitoring cable.

The a-c voltmeter is similar to the BTE voltmeter. It consists of a d-c differential amplifier with negative feedback. R5 provides d-c feedback whereas the meter full wave average rectifier circuit containing the meter provides current feedback. Resistors R8 and R9 sets the closed loop gain of the amplifier, thereby changing measurement range. Full scale ranges are 1v and 3v.

Mechanical Design.

The GSE is designed for rack mounting, consistent with payload system test equipment requirements. Figure 33 shows a completed

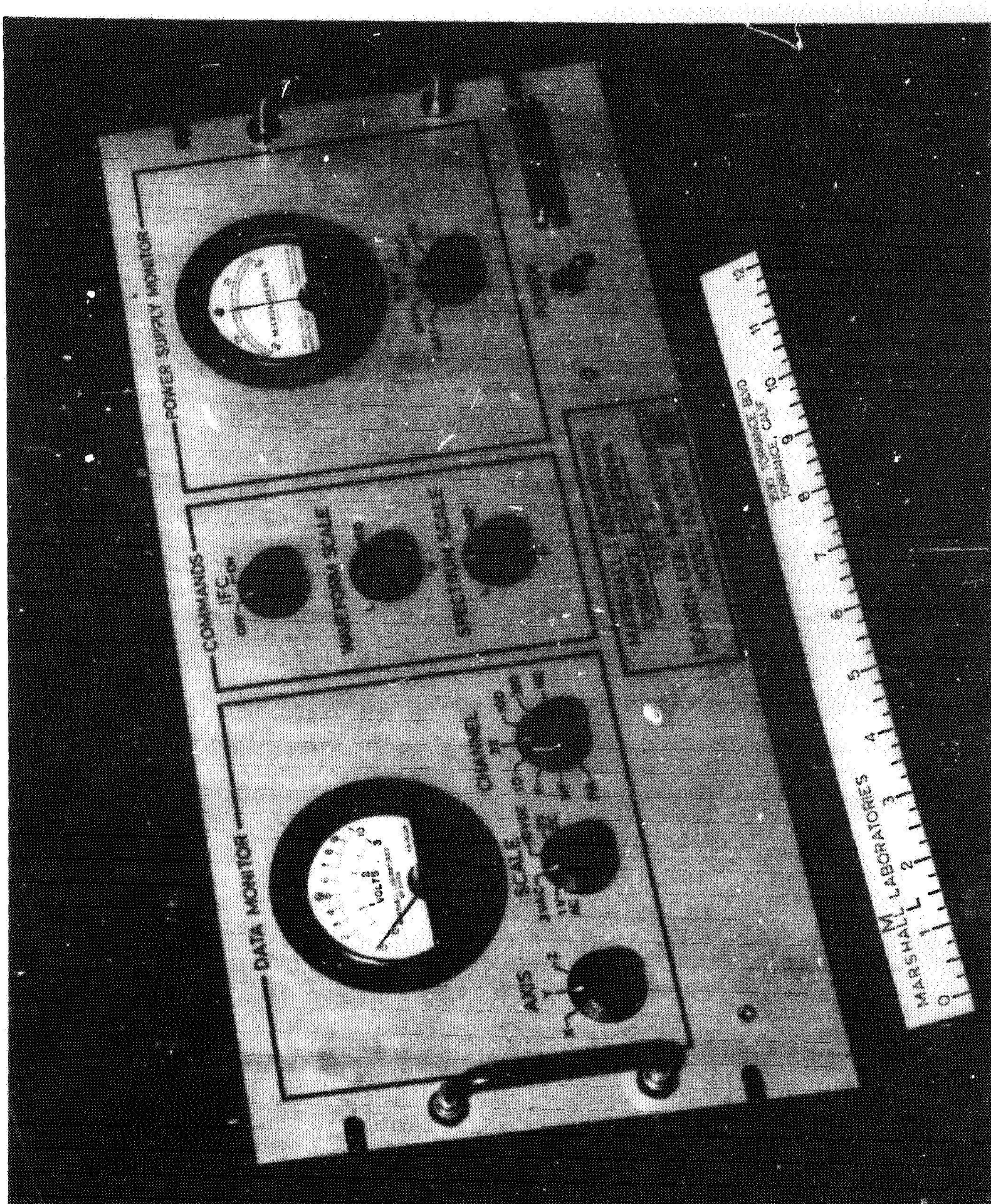


Figure 33. Search Coil Magnetometer Test Set, Model ML 170-1

assembly. The circuit components (other than those mounted on the panel) are assembled on a printed circuit board and attached to the panel.

SUMMARY

The probe assemblies described in this report performed satisfactorily, however, there are several changes which could be made to improve their characteristics. Listed below are some of the possible improvements.

1. The cross section of the core material can probably be probably be decreased by at least a factor of four which would decrease the weight of the core by the same factor. This would decrease the sensitivity only slightly (sensitivity is proportional to area raised to the 0.2 power).

2. Fringing effects cause the sensitivity of those winding near the end of the core to be less effective than those near the center. An increase in sensitivity is therefore possible by decreasing the length of the overall coil from the present eight inches to something in the order of two inches.

3. The gold plating on the probe assemblies was the result of an early EP5 design which would leave the probes exposed. The final EP5 configuration enclosed the probe mounting area therefore negating the need for the gold plating. In addition to being unnecessary, the plating is somewhat suspect from an operational standpoint since the gold requires a thin nickel undercoat which may have changed the overall magnetic characteristics.

The preamplifiers performed satisfactorily only after temperature compensating networks were added to each of them. This was found to be necessary due to the inability of the internal heater to maintain a suitable operating temperature when not in a vacuum (the aluminized mylar is almost useless under atmospheric pressure).

Several areas of possible improvements to the preamplifiers could well be investigated for future systems. These are listed below:

1. When driven by probe assemblies, some of the preamps had a frequency response which differed from others. An investigation should be made to determine the cause of this anomaly.

2. The preamp construction method using point-to-point soldering could be improved by using welded interconnections.

3. The epoxy potting compound is virtually impossible to rework and is also relatively heavy. Future systems might well use foam as a replacement.

4. A slight increase in the height of the preamplifier housing would facilitate the final assembly.

The main assembly required several modifications before it was functionally acceptable. These included the addition of filters on the power and sync signals inputs to decrease noise; the addition of a logic module to enable proper performance of the Waveform Channel bandwidth selection; and the addition of the Band Reject Filters. Other areas which performed satisfactorily but, which could be improved, are listed below.

1. The bridged-tee networks in the Spectrum Analyzer would be more stable if its complement were used (interchange resistors and capacitors).

2. The nickel ribbon used in the welded modules could be replaced with Alloy 180 to decrease the magnetic moment.

3. The use of RF filters on the interface lines should be avoided.

4. Double sided PC boards with plated through holes should not be used in the future. They should be replaced with either single sided PC boards or a welded matrix.

5. The replacement of epoxy potting for the modules with a light weight foam should be considered for future systems.

The system test equipment performed satisfactorily but could be improved as noted below.

1. The fluxtanks were found to be of little use due to the loading effect they had on the search coils.

2. The DC metering circuit required constant zeroing due to drift. A chopper together with an AC meter would be much more stable.

3. The equipment should incorporate facilities for operating directly from the AC line rather than only from batteries.

4. The box used for test points is clumsy and did not contain all signal leads.

5. The location and nomenclature on the controls left much to be desired from a human engineering standpoint and could be considerably improved.

6. The construction and wiring technique should be improved to simplify assembly.

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APPENDIX A

MDL 50430	Triaxial Search Coil Magnetometer, Model ML 140-1
MDL 50432	Preamp Assembly, Model ML 150-1
MDL 50471	Search Coil Assembly, Model ML 157-1
MDL 50355	BTE, Model ML 145-1
MDL 50599	GSE, Model ML 170-1

MDL 50430 | A

MASTER DRAWING LIST

MARSHALL LABORATORIES

IDENTIFYING NAME TRIAXIAL SEARCH COIL MAGN. ASSY. MODEL ML 140-1

ISSUE DATE 13 September 1962 REVISION DATE 13 September 1962 EFFECTIVITY 1 & UP SHEET 1 of 2

LIST NO.	Assembly Position 1	2	3	4	5	6	7	8	9	DRAWING NUMBER	CHG. LTR.	DRAWING TITLE	Dwg Size	No. Sht
1	1									50430-101		Magnetometer Assy - Triaxial Search Coil	D	1
2		R								50327		System Wiring Diagram	C	1
3		R								50431		Envelope-EGO Triax. Search Coil Magn.	D	1
4		R								L50374		Layout - EGO Triax. Search Coil Magn.	J	1
5		R								50357		Schematic - EGO Triax. Search Coil Magn.	J	1
6														
7														
8														
9		R								S40004		General Spec. For Board, Etched, Printed Ckt.	A	11
10		R								S40072		Spec. Fabrication & Workmanship of Elect. Flt. Equip	A	22
11		R								S40091		Spec. Conformal Coating		
12														
13														
14														
15		1								50441-101		Housing Assy - Triax. Search Coil Magn. (Y, Z, Axis)	J	1
16			1							50493-1		Housing - " " " " "	J	1
17			1							50493-2		Cover " " " " "	J	1
18			4							50493-3		Spacer " " " " "	J	1
19			5							50493-4		Spacer " " " " "	J	1
20			1							50442-1		Circuit Board " " " " "	D	1
21				R						T50443		Circuit Master " " " " "	D	2
22			1							50479		Insulator " " " " "	C	1
23			3							SP30118E-27-59-3		Insulative Sheet	B	1
24			A/R							SP30126E13P24-5		Insulative Washer	B	1
25			10							W4013X1		Spectrum Analyzer Module	D	1
26			8							W4021X1		Gain Change Amplifier Module	D	1
27			2							W4022X1		Waveform Output Module	D	1
28			1							W4023X1		Level Sensor Module	D	1
29			1							W4026X1		Bias Power Supply Module	D	1
30			1							W4027X1		Dual Inverter Module	D	1
31			2							W4028X1		Flip Flop Module	D	1
32			1							W4029X1		Relay Diode Module	D	1
33			2							W4032X1		Dual Band Pass Filter Module	D	1
34														
35														
36														

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MARSHALL LABORATORIES

IDENTIFYING NAME TRIAXIAL SEARCH COIL MAGN. ASSY. MODEL ML 140-1

ISSUE DATE 13 September 1962 REVISION DATE 13 September 1962 EFFECTIVITY 1 & UP SHEET 2 OF [illegible]

LIST NO.	1	2	3	4	5	6	7	8	9	DRAWING NUMBER	CHG. LTR.	DRAWING TITLE	Dwg Size	No. Sht.
37		1								50444-101		Housing Assy - Triax. Search Coil Mag. (X Axis)	J	1
38			1							50449-1		Housing - " " " " "	J	1
39			1							50449-2		Cover " " " " "	J	1
40			1							50449-3		Cover " " " " "	J	1
41			2							50449-4		Spacer " " " " "	J	1
42			1							50449-5		Spacer " " " " "	J	1
43			6							50493-3		Spacer " " " " "	J	1
44			1							50493-4		Spacer " " " " "	J	1
45			1							50447-1		Circuit Board " " " " "	C	1
46				R						50448		Circuit Master " " " " "	D	2
47			1							50480		Insulator " " " " "	C	1
48			2							SP30118E27-59-8		Insulative Sheet	B	1
49			1							SP30126V18P48-5		Insulative Washer	B	1
50			5							W4013X1		Spectrum Analyzer Module	D	1
51			4							W4021X1		Gain Change Amplifier Module	D	1
52			1							W4022X1		Waveform Output Module	D	1
53			1							W4032X1		Dual Bandpass Filter Module	D	1
54			1							W4029X1		Relay Diode Module	D	1
55			1							W4038X1		Gain Indicator Module	D	1
56			1							50439-1		Clamp - Transistor Mounting	A	1
57			1							50511-101		Power Supply - Triax. Search Coil Magn.	D	1
58				1						50445		Circuit Board - " " " " (Pwr. Sup)	C	1
59					R					T50446		Circuit Master " " " " " "	D	2
60				1						SP30064		Transformer	B	1
61				1						W4014-1		Fine Regulator Module	D	1
62				1						W4015X1		Pre-Regulator Module	D	1
63				1						W4016X1		D/C Voltage Converter Module	D	1
64				1						W4024X1		Capacitor Module	D	1
65				1						W4034X1		Power Supply Diode Module	D	1
66				1						W4039-1		6 Volt Regulator Module	D	1
67				1						SP 30090		Transformer	B	1
68														
69														
70			A/R							SP30126E13P24-8		Insulative Washer		
71														
72														

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MDL 50432 | A

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MARSHALL LABORATORIES

IDENTIFYING NAME PREAMP ASSEMBLY - SEARCH COIL EGO MODEL ML 150-1

ISSUE DATE 13 September 1962 REVISION DATE 13 September 1962 EFFECTIVITY 1 & UP SHEET 1 OF

LIST NO.	ASSEMBLY POSITION 1	2	3	4	5	6	7	8	9	DRAWING NUMBER	CHG. LTR.	DRAWING TITLE	DWG Size	No Shts
1	1									50432-101		Preamp Assembly	D	1
2		1								50516-1		Box	D	1
3		1								50516-2		Cover	D	1
4		3								50561-101		Preamp Module	D	1
5		1								50562-101		Heater Module	D	1
6														
7		R								50526		Envelope-Search Coil Pre-Amp, EGO	C	1

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D. Casey

MASTER DRAWING LIST

MARSHALL LABORATORIES

IDENTIFYING NAME SEARCH COIL ASSEMBLY - EGO MODEL ML-157-1

ISSUE DATE 13 September 1962 REVISION DATE 13 September 1962 EFFECTIVITY 1 & UP SHEET 1 OF

LIST NO.	ASSEMBLY POSITION 1	2	3	4	5	6	7	8	9	DRAWING NUMBER	CHG. LTR.	DRAWING TITLE	Dwg Size	No. Sht.
1	1									50471-101		Search Coil Assy.	D	1
2		1								50470-101		Housing - Search Coil Assy.	D	1
3			1							50470-1		Box	D	1
4			1							50470-2		Cover	D	1
5		8								SP30117		Coil Assy.	A	1
6			8							T40232		Coil Bobbin	A	1
7		1								50463		Magnetic Core	A	1
8														
9		R								S40091		Conformal Coating Spec.		
10		R								S40092		Foaming Spec.		
11		R								T50477		Potting Fixture		
12														
13		R								S40072		Spec-Fabr. & Workmanship Elect. Flt. Equip.	A	22
14		R								50469		Envelope - EGO Triaxial Search Coil	C	1
15														
16														
17														

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MDL 50355

RELEASED NOV 28 1962

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MARSHALL LABORATORIES

IDENTIFYING NAME Test Set Assy--EGO Search Coil Magnetometer MODEL ML 1451

ISSUE DATE REVISION DATE EFFECTIVITY SHEET 1 OF 1

LIST NO.	ASSEMBLY POSITION 1	2	3	DRAWING NUMBER	CHG. LTR.	DRAWING TITLE
1	1			50355-101		Test Set Assy--EGO S/C Magn.
2		1		50355-1		Bracket, Front
3		1		50355-2		Bracket, Rear
4		1		50355-3		Carriage
5		2		50355-4		Spacer
6		1		50355-5		Clip
7		1		50355-6		Plate
8		1		50355-7		Clip
9		1		50355-8		Cover, Upper
10		1		50355-9		Cover
11		1		50355-10		Base
12		2		50355-11		Retainer
13		2		50355-12		[illegible]
14		2		50355-13		[illegible]
15		2		50355-14		[illegible]
16		1		50355-15		Panel, Front
17		1		T50366-101		[illegible]
18						
19		1		50455-101		Printed Circuit Brd. No.1
20			1	50455-1		Board
21			R	T50452		Circuit Master
22			3	SP30100		Diode
23			2	SP30061		Transistor
24			26	SP30126E4P12-5		Washer
25			R	S40004		Spec. Printed Circuit Brd.
26		1		50462-101		Printed Circuit Brd. No.2
27			1	50462-1		Board
28			R	T50460		Circuit Master
29			2	SP30100		Diode
30			12	SP30061		Transistor
31			R	S40004		Spec.--Printed Circuit Brd.
32		R		50485		Electronic Schematic
33		R				Layout--Converted to Assy DWG.

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MDL 50599 [illegible]

(E) RELEASE 10-4-62

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MARSHALL LABORATORIES

IDENTIFYING NAME TEST SET SEARCH COIL (EGO) MAGNETOMETER MODEL ML 170-1

ISSUE DATE 21 Sept. 62 REVISION DATE 21 Sept. 62 EFFECTIVITY 1&UP SHEET 1 OF 1

LIST NO.	ASSEMBLY POSITION 1	2	3	4	5	6	7	8	9	DRAWING NUMBER	CHG. LTR.	DRAWING TITLE			
	1									50599-101		Test Set Search Coil (Ego) Magnetometer			
		1								50599-1		Cable			
		1								50599-2		Bracket, Relay Mtg.			
		2								50599-3		Bracket, Batery Cup Mtg			
		1								50594		Front Panel Test Set Search Coil Magnetometer			
		1								50602-101		Printed Circuit BD. Test Set S.C. Magnetometer			
			1							50602-1		Board			
			1							[illegible]50601		Circuit Master, P/C Board Test Set S. C. Magnetometer			
		1								50[illegible]		Schematic Ego Search Coil G.S.E.			

(B) DS 10-2-62 PREPARED BY [illegible]